The Use Of Analyst-User Cognitive Style Differentials To Predict Aspects Of User Satisfaction With Information Systems

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

SIGNED:

DATE:

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Participating Organizations / . . .

Participating Organizations

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Since this study involved human subjects, the appropriate ethics approval was sought from the Auckland University of Technology Ethics Committee. The necessary approval was granted on 20 May 2004 for the period 20 May 2004 to 20 May 2006. The approval number is: 04/49.

ABSTRACT

This study was primarily an empirical investigation in the field of Information Systems (IS) and the related fields of occupational psychology and management. It focussed specifically on the concept of *user satisfaction*, the construct of *cognitive style* as applied to users and systems analysts, and their interrelationships. Prior studies were found rarely to investigate the changes in user satisfaction during system usage. Further, any reference to cognitive style in the IS literature proved to be sparse, open to question and discouraging in terms of its value. By developing and using a new instrument, the System Satisfaction Schedule, or SSS, the present study was able empirically to demonstrate clear patterns of changing user satisfaction during system usage. These were demonstrated, both as a general trend and in terms of its relationship to the cognitive styles of the key players (analyst and user) involved in system development and maintenance. Cognitive style was measured using Kirton's Adaption-innovation Inventory, or KAI. This study was thus able to suggest new rules for system development based on the assessments of the cognitive styles of both users and systems analysts. These rules focussed primarily on simple team choice: which analyst to put with which user. However, inferences for larger system development teams were drawn and suggestions for further research duly made. The present study thus also contributes to the successful practice of system development.

To give effect to the above, this study set out to investigate empirically the way user satisfaction changes over 1½ to 2 years of system usage and, as mentioned above, the way user satisfaction is impacted by the cognitive styles of the user and the systems analyst. Most significantly, relationships were studied between user satisfaction and the *difference* in cognitive style between the analyst and user. It was found that user satisfaction generally rises linearly with usage, and that while the size of the analyst-user cognitive differential does negatively impact user satisfaction over most of the time of system use, this effect is only particularly strong for two short periods; one within the first four months of usage and the other in the last three. From these results the new rules for system development mentioned above, followed. In terms of

the decline of users' mean perceived severities of *individual* problems, the exponential decay and reciprocal models were found to fit the data the best.

This study developed a new model for the motivation to use, develop or maintain a system (the Mechanical Model), based on its own results and Herzberg's two-factor theory of motivation. In this, Herzberg's hygiene factors have been replaced with the concept of *dissatisfiers*. These are measured as expressions of dissatisfaction as and when they occur. Their use removes the researcher's need, when designing user satisfaction instruments, to speculate on *complete* lists of factors which *may* satisfy users, and which may date as technology and other contextual factors change.

Chapter 1

Introduction to the study

1.1 Introduction

This study focused on the changes in user satisfaction with system usage, and was further motivated by the conjecture that one might be able to use cognitive style tests as a means of selecting an appropriate analyst (formal definition in Chapter 2, Section 2.1) to service the system needs of any given user. As mentioned below, it thus helped not only to fill gaps identified in the research literature but also to offer recommendations for IS development team choice. As discussed in Section 1.1.2 and Chapter 2, there is a general recognition in the literature that user satisfaction is a significant ingredient of system success (see Chapter 2, Table 8). However, this study could not find any recent empirical IS studies involving cognitive style and its relationship to user satisfaction.

In context, this study was primarily an empirical investigation in the field of Information Systems (IS) and the related fields of occupational psychology and management. As mentioned above, it focussed specifically on the concept of *user satisfaction*, the construct of *cognitive style* as applied to users and systems analysts, and the cognitive style / user satisfaction nexus. As a starting point, the relevance of the notions of *cognitive style* and *user satisfaction* to IS research were investigated.

1.1.1 The significance of cognitive style in IS research and practice

The term "cognitive style" remains in significant use in current scholarly literature and several recent articles propose definitions for it. A number of optional definitions are explored in Chapter 2, Section 2.2.2. After due consideration, they all were found to approximate to two statements by Kirton:

(1976): "An individual's cognitive style is their preferred approach to problem-solving"; and

(2003): "An individual's cognitive style is a *stable*, *preferred* manner in which (s)he brings about change."

An IS person, by developing a system, brings about change in the user's environment, hence the *manner* in which this is done clearly could affect the user and his/her enthusiasm for using the new system. Following from Kirton's (2003) definition, the analyst's cognitive style dictates the *manner* in which they *will probably* go about bringing about change, in this case, by way of developing a new system. The user may or may not be particularly amenable to this manner. Hence, it was conjectured, the analyst's cognitive style probably will impact the user's perceptions of the development effort and the resulting system. Insofar as system development and usage are concurrent (see below), they will also influence the way systems are perceived during system usage. This may also help to explain the prolific use of the term "cognitive style" in current scholarly IS literature.

There is evidence that the user's cognitive style also plays a significant role in user satisfaction and consequent system success. For instance, Mullany (1989) demonstrated a positive association between the absolute analyst-user differential (or cognitive gap) and user resistance. The former he measured using Kirton's Adaption-Innovation Inventory (1976) or KAI, applied to both users and analysts. The latter was measured as a number of weighted complaints made by the user in private regarding problems associated with the system. The larger the cognitive gap, the more complaints were made, and the more intense they tended to be. The study argued that a user tends to be *least dissatisfied* when served by a systems analyst/developer of similar cognitive style, since the user will then recognise an approach to problem-solving in the analyst with which they are familiar and a consequent system solution which they are likely to trust (see Chapter 2, Section 2.2.4). The present study examined cognitive style, and its impact on user satisfaction over a significant period of system usage time; not development time. However, the fact that an analyst develops a system implies that his/her cognitive style is to an extent imposed on the user throughout system usage. Furthermore system development usually accompanies system usage by way of system evaluation and maintenance. Hence significant personal interaction between the analyst and user normally occurs, further enhancing any effect of similarities or dissimilarities of personality, including cognitive styles.

Other than the above and some further exploratory studies by Mullany and one by Hsu (1993) cited by Gregor and Benbasat (1999), no empirical results shedding light on the role of cognitive style in IS research were found. Some other studies related to cognition, the parent term for cognitive style (for example, Tan and Hunter, 2002), or other related concepts such as cognitive process (Ramaprasand, 1984), were found. Tan and Hunter (2002) demonstrated the use of Kelley's (1955) repertory grid technique for exploring cognition in information system research and practice. Where cognitive style is pursued as a guide to IS research and practice, however, the literature tends to be somewhat discouraging. Huber (1983), for example, suggests that cognitive style theory has contributed nothing to Management Information System (MIS) or Decision Support System (DSS) design and probably never will. Ramaprasand (1987) challenges Huber on the grounds that *cognitive process* is the more appropriate factor when dealing with IS success and that the latter approach should yield fruitful results. Nothing of significance along these lines was found in later scholarly literature, however. Carey (1991), in a literature survey and discussion of cognitive style theory application in IS research, calls for this direction not to be abandoned. However, her study did not clearly suggest how the various cognitive theories she discusses could be used. She does not mention Kirton's Adaption-Innovation (A-I) theory, which Mullany (1989) had employed to obtain the positive results discussed above.

As previously mentioned, the use of the terms *cognitive* and *cognitive style* have become much used in scholarly IS literature, evidently on the basis that they are well-understood terms for which widely accepted definitions exist. Trauth and Cole (1992), for instance, suggest that different user interfaces should cater for the

> "cognitive styles of end-users"

without further discussion of the meaning of "cognitive style". This type of usage was found to be typical and current. Where empirical studies or literary analyses exist, they tend to exhibit rather weak results and hence support the misgivings of Huber (1983) mentioned above. Robey (1992), for instance, defends Huber's (1983) position and suggests that

> "simple dichotomies of cognitive style";

that is, simple bipolar measures, should be abandoned in favour of more complex models of human cognition. Alavi and Joachimsthaler (1992), in an analysis of DSS implementation research literature, suggest that a disproportionate amount of attention has been placed on cognitive style research in the DSS field and that the impact of cognitive style on DSS implementation success is relatively small.

Hsu (1993), in an empirical study, established a relationship between cognitive style and cognitive restructuring skills, and thus to cognitive learning theory. Cognitive style was measured using the Group Embedded Figures Test (GEFT) of Oltman, Raskin, and Witkin (1971). Hsu found that field-independents, as measured by this instrument, learned better with flexible (user invoked) and justified explanations than they did with rule-trace explanations. However, Gregor and Benbasat (1999), in a discussion of Hsu's study suggest further research in the cognitive style area for IS. The present study found little evidence that this had been undertaken.

Te'eni, (2001), notes a widespread decrease in research into individual differences in information systems during the 1980s, following Huber's (1983) conjectures on the future of cognitive style in MIS and DSS design. However, he suggests that cognitive styles in relation to communication theory is

> "an untapped avenue for future research that may, after all, lead to individually tailored systems",

particularly in relation to what he calls

> "the new virtual organization in which the bulk of the communication cannot rely on face-to-face communication".

The current importance of cognitive style appears to be little more than a matter of usage and conjecture on the part of some scholars such as Carey (1991), Gregor and Benbasat (1999) and Te'eni (2001) that cognitive styles might lead to worth while results eventually. Scholarly IS studies continue to use the terms *cognitive* and *cognitive style* as though they have commonly accepted meanings and validities. However, few empirical studies specifically clarify the concept. Furthermore, Kirton's (1976) A-I theory appears to be under-represented in IS studies. This seems anomalous considering that his work has been much covered in scholarly psychological and management literature ever since 1976. In confirmation, Desmedt and Valcke (2004) found that Kirton's A-I theory and the KAI to be the third most prolific in scholarly literature after Witkin's and Kagan's theories and instruments.

Buffinton, Jablokow and Martin (2002) note that Kirton's A-I theory

> "is well established and has been validated in practice for over 25 years, with hundreds of international journal articles and graduate theses devoted to its study and application."

Conjectures by scholars such as Carey (1991), Gregor and Benbasat (1999) and Te'eni (2001), proposing that cognitive style is worth pursuing, at least in some IS context, together with the under-representation of A-I theory, suggest a gap in scholarly IS literature. The present study helps to fill this with the further exploration of the use of A-I theory in IS research. Considering the growing usage of terms such as "cognitive" and "cognitive style" in contemporary scholarly IS literature, more work in this area, as applied to IS, appears called for, and this study essayed to make such a contribution.

1.1.2 The significance of user satisfaction in IS research and practice

As discussed in Chapter 2, Section 2.3, the significance of user satisfaction revolves upon its link to *system success*. Scholarly literature exists which equates user satisfaction to system success or at least as a *key element* of system success (see Chapter 2, Table 8 for an assortment of studies making such claims). For example, DeLone and McLean (1992) suggest that user satisfaction is

> "probably the most widely used single measure of IS success".

They submit three reasons for this. First, that the term *satisfaction* has

> "a high degree of face validity. It is hard to deny the success of a system which its users say that they like."

Second, the Bailey and Pearson instrument and its derivatives have

> "provided a reliable tool for measuring satisfaction and for making comparisons among studies."

Third, that other measures of user satisfaction and system success are highly unsatisfactory, being

> "either conceptually weak or empirically difficult to obtain"
> (DeLone and McLean, 1992).

Additionally, it is difficult to see how a system which the users find overtly unsatisfactory can be successful, unless driven by an autocracy *and* the extra resource usage associated with the policing of its use. In general, then, the optimisation of user satisfaction implies a happier work environment with lower overheads. Table 9 of Chapter 2 lists several scholarly studies over the period 1981 to 2005, which purport to measure user satisfaction or related constructs, thus underlying this perceived importance in IS research.

An early difficulty identified by this study and discussed in Chapter 2, Section 2.3, is the meaning of the term *user satisfaction* itself. It was later deduced that a user cannot assess their satisfaction with a system of which they have had no experience. Hence, for this study:

> ***User satisfaction* implies a summary of those factors in a user's experience of the system which satiate his/her job needs *after* some experience of using it.**

(For main reference, see **American Heritage Dictionary of the English Language, 2000**, and Chapter 2, Section 2.3 for details.**)**

The present study (see Chapter 2, Section 2.3), despite the numerous pieces of scholarly research cited in Table 9, found that user satisfaction has not followed an evolutionary process parallel to that exhibited by cognitive style (see Section 2.2). Rather, various authors have invented satisfaction instruments which are open to question, having employed little psychological or management theory in their development. Hence it was found that while much interest continues to be shown in the construct of user satisfaction in scholarly IS literature, little progress has been made in developing a generally agreed upon definition for this construct. Although Cheney, Mann and Amoroso (1986) called for more empirical research on the factors which influence the success of end-user computing, little subsequent effort in this direction was found in the IS literature. This opened the way for a further attempt by the present study: the development of its own user satisfaction measure, the "System Satisfaction Schedule" (SSS) (see Chapter 4, Sections 4.3.6, 4.3.7, 4.3.8 and Appendix 1.2 for details).

In short then, the literature surveyed suggests that user satisfaction is important to maintain a happy work environment for users and their colleagues; is perceived to be important to minimise overheads associated with employee dissatisfaction; and is further perceived to be important to IS research by several scholars. However, no universal or unified definition of the construct could be found beyond DeLone and McLean's (1992)

> " high degree of face validity",

giving the room needed by this study to develop its own meaning and measure of user satisfaction, the SSS. This gives a *user satisfaction score* denoted elsewhere in this thesis by the *statistic* S; that is, a *descriptive measure* of overall satisfaction at a point in time.

1.2 The development of the research questions

This study commenced with an investigation into three categories of literature:

- The meaning of the terms 'cognition' and 'cognitive' as used by human science researchers since the early to mid twentieth century;
- The emergent meaning and measures of cognitive style; and
- IS user satisfaction, its significance and measurement.

In addition to the lack of usage of A-I theory discussed above, two principal gaps in scholarly IS literature, were identified:

1) A lack of recent enquiries into the relationship between user satisfaction and the cognitive styles of those participating in system development and/or usage (Banker and Kauffman, 2004); and
2) Little discussion of patterns or principles inherent in the changes of user satisfaction over system usage time. Such discussion, where it occurred, tended to be sparse, anecdotal and speculative. Additionally, the properties of user satisfaction tended to be inferred from research in other disciplines; for example, the McKinney, Yoon and Zahedi (2002) model based on Oliver's (1980) model of *customer* satisfaction (see Chapter 2, Section 2.3.1 for details.)

The conclusion was reached that of all the instruments in current use to measure *cognitive style*, the KAI was suited to the needs of this study. This follows chiefly from the fact that the KAI is uncontaminated by elements of *cognitive level*, (Kirton, 1999. Also, see Chapter 2, Sections 2.2.4, 2.2.4.1, 2.2.4.2 and Table 6).

Further scholarly IS literature was surveyed, which examined the significance and measure of user satisfaction. The conclusion was reached that none of these is suitable for repeated measures of satisfaction with the same user over time, as errors of attrition would possibly contaminate the results. Furthermore, for all but three studies (Mullany, 1989, Zhang and von Dran, 2000, and Cheung and Lee, 2005), there was little underpinning by recognised psychological or management theory.

Based on the study objectives and the gaps found in the IS literature surveyed as discussed above, four research questions were formulated (see Chapter 2, Section 2.5). For example, the sparse coverage in scholarly literature of patterns and principles inherent in the changes of user satisfaction over system usage time, prompted the following research question:

1) ***How, in general, does a user's satisfaction with a system change over time?***

The prior study by Mullany (1989) showed a positive relationship between user complaints and the analyst-user cognitive gap. If it is assumed that complaints, measuring dissatisfaction, are the antipode of user satisfaction, then a negative relationship between the cognitive gap and user satisfaction would be expected. Hence the next research question:

2) ***Does the cognitive differential between analysts and users (Kirton's (1999) 'cognitive gap') yield advance predictions of overall user satisfaction with a given system?***

Little was found in contemporary scholarly literature exploring any patterns or principles inherent in the changes of user satisfaction over system usage time. At the most, two-period studies were conducted to establish the test-retest reliabilities of user satisfaction instruments; for example, the (1989) study by Galletta and Lederer, which demonstrated the test-re-test reliability of Baroudi et al.'s (1983) User Information Satisfaction measure (see Chapter 2, Section 2.3.1 for details). Other than instances of these, empirical time-wise studies of system development or usage and cognitive style were singularly absent from the literature. If such patterns and principles were found to be evident, then they could well suggest new recommendations for *system development* efforts, so as to enhance user satisfaction during *system usage*. The research question based on this was:

3) ***What new rules for system development would descend from cognitive style and its measurement? For example, do new rules emerge for the choice of systems analyst, based on the cognitive styles of individual users and analysts?***

As the research procedure was developed, it became evident that individual user complaints were going to be recorded and their severity rated over the time period of the survey (see Chapter 4, Section 4.3.9). This provided an opportunity to investigate one area for which no prior empirical research was found: how the severities of individual user complaints vary over time. This suggested the fourth research question:

4) ***How does the user's perceived severity of system problems change with time?***

Hypotheses were developed to help answer some of the research questions outlined above. The full development of these is covered in Chapter 3, Sections 3.3.1.4 to 3.4. These hypotheses offered conjectures concerning:

1) the trend of the mean S over time (see Chapter 3, Section 3.3.1);
2) the relationship between the absolute (algebraically unsigned) analyst/user cognitive style difference (cognitive gap) and overall user satisfaction (see Chapter 3, Section 3.3.2.2);
3) the relevancy of the absolute cognitive gap, algebraic cognitive gap, user cognitive style and analyst cognitive style over the time domain (see Chapter 3, Section 3.3.2.3); and
4) the shape of the time series curve for the mean dissatisfaction with *individual factors* identified by the user (see Chapter 3, Section 3.4).

It was clear that many of the definitions of cognitive style found in the literature were vague and open to question. However, after due research and analysis of the literature (see Sections 1.1.2 and 1.2), it was clear that they all approximate at least one of two definitions offered by Kirton:

(1976): "An individual's cognitive style is their preferred approach to problem-solving."; or

(2003): "An individual's cognitive style is a *stable*, *preferred* manner in which (s)he brings about change."

After the examination of several descriptions and measurement techniques found in the literature, together with input from the applied psychological literature, *user satisfaction* was defined as:

A lack of user dissatisfaction and complaint (see Chapter 3, Section 3.3).

The associated measuring instrument, the SSS, was constructed and pilot-tested as part of this study (see Section 1.1.2).

1.3 A summary of the research methodology

The methodology of the research procedure involved two phases; data collection and data analysis (see Chapter 4, Sections 4.3 and 4.4 for details). During the data collection, the KAI was used to measure analyst and user cognitive styles (see Chapter 3, Section 3.3.2 and Appendix 1.1 for the format of the instrument), and the System Satisfaction Schedule (SSS) to measure user satisfaction (S), over time (see Appendix 1.2 for the instrument).

Since several users can use one system and several systems can be used by one user, the combinations of users and systems proved to exhibit a many-to-many relationship. This study therefore took the basic research unit to be a "user-system", or US (see Chapter 3, Section 3.2). The research sample was 62 USs drawn from 12 organisations distributed over South Africa and New Zealand. Kirton's KAI was used to measure each user's and each analyst's (or developer's) cognitive style. At an initial face-to-face interview, the user's S-Score was determined using the SSS. For details of the research procedure, see Chapter 4, Sections 4.3.9 and 4.4.

The data thus made available was four sets of initial readings for each sample US, as follows:

- the number of days since the user began (or until the user did begin) interacting with the working system,
- the user's cognitive style as a KAI-score,
- the analyst's cognitive style as a KAI-score, and
- the user's satisfaction with the system as an initial S-Score.

Thereafter, with the aid of the telephone, user S-Scores were obtained for the correlative systems at approximately 90 day intervals. A minimum of three and a maximum of seven readings were taken for each US. Under the assumption made in Section 1.1.2 that a user must have had some experience of the system before being in a position to judge their satisfaction, the study defined day zero as the first day on which the user made use of the system. However, a difference of opinion between organisations and users regarding the start dates of usage were noted in most USs studied. In such instances, the user's opinion was taken as correct. In five such cases, usage occurred 1 to 116 days later than the organisation had specified. The 333 S-Score readings made, spread over the 62 USs, were thus plotted on a common time domain from -116 to 847 days. However, for the actual analysis readings occurring prior to day zero were ignored. As fewer than 10 readings were present after day 730, readings made later than this were also ignored. This gave 320 remaining readings spread over a time domain of 731 days, numbered 0 to 730 inclusive, which is effectively two years. S was found usually to have a range of 0 to 40 units. In fact 40 cannot be exceeded, but one unexpectedly low S-value of -12 was recorded. For further details, see Chapter 5, Section 5.2.

1.4 Significance and key contributions

1.4.1 Significance of this study

This study contributes to knowledge by establishing patterns of changing user satisfaction over the time of system usage, and the variant impact of analyst and user cognitive styles over the period of system usage. It further yields recommendations for effective systems analyst choice, given the cognitive style of the user. It also has produced a new instrument, the SSS, which is robust to changes in technology and which can be used repeatedly with the same respondent over time. It was thus possible to conduct this study, which is a time-wise analysis of user satisfaction and how cognitive style differences impact this.

1.4.2 General results

The present study found that user satisfaction, S, in general rises linearly with time. It also found that the absolute cognitive differential (cognitive gap) is negatively associated with the Mean, Median and Maximum of the overall user-S. Though the corresponding association was statistically significant, it was not found to be particularly strong (see Chapter 5, 5.3.1). The exponential decay and reciprocal models were found to fit the individual problem severities best, and did not differ significantly from one another (see Chapter 6, Section 6.2.5). It was thus concluded that either model explains the mean reduction of perceived problem severity equally well.

The absolute analyst-user cognitive gap was found to be weakly negatively associated with the S-Score over most of the time domain. However, in two critical regions, the neighbourhoods of day 85 and day 652 (see Chapter 5, Section 5.4.1) the impact of the absolute cognitive gap was found to be particularly high. In the case of the first critical region, it was concluded that a large cognitive gap will cause great user dissatisfaction, and may lead to a young system stalling. In the late critical region, it was similarly concluded that user dissatisfaction, just prior to US termination, is strongly negatively associated with the absolute cognitive gap. The effect of the cognitive gap in these critical regions was found to be asymmetric, the user tending to complain less if the analyst is more adaptive than him/her than in the reverse scenario (see Chapter 5, Sections 5.4, 5.4.1, 5.4.2, 5.4.3 and 5.4.4).

1.4.3 New rules for system development

The latter part of the analysis enabled the following new rules for system development (and consequent user satisfaction during usage) to emerge:

1. ***As mean satisfaction was found to rise throughout system usage, in order to optimise user satisfaction, the practitioner should look for strategies that will keep a user using the same system for as long as possible.***
2. ***Minimising the absolute analyst-user cognitive gap <u>positively impacts</u> user satisfaction. To optimise user satisfaction and US life, the analyst should be chosen to have a similar cognitive style to the user.***
3. ***In the critical regions in the early and late lives of system usage, an analyst with a more adaptive cognitive style (lower KAI score) than the user reduces user dissatisfaction. To optimise user satisfaction in the two critical regions early and late in system usage (around 85 and 652 days), the analyst should be selected to be more adaptive than the user.***
4. ***Adaptive analysts are a better choice in the early life of a user's experience with a system than are innovative analysts (with higher KAI scores), since the former (at least in respect of system development and the early stages of system usage) are more successful agents for change.*** (see Chapter 6, Section 6.2.4)

Rule 4 above does not imply that the analyst should necessarily be changed, but rather, that if the cognitive styles of user and analyst cannot be matched exactly in accordance with rule 3, then one should err on the side of a more adaptive analyst, with a lower or slightly lower KAI score than the user's.

1.4.4 A new motivational model for system use and development

In Chapter 6, Section 6.3, this study suggests a new model for system usage and development, which adapts Herzberg's two-factor theory of motivation to a model based metaphorically on a simple mechanical machine (see Chapter 6, Section 6.3.1 and Figures 21 and 22). The present study found empirical evidence for the proposed model as applied to system usage (see Chapter 6, Section 6.3.2), but calls for further research to substantiate it for system development (see Chapter 6, Section 6.5.6).

1.5 Outline of the thesis

This thesis consists of six chapters, a bibliography and several appenda. Each chapter begins with an introduction and ends with a summary. These are intended to facilitate the access of specific material as required by the reader. To assist the reader further, a brief synopsis of each chapter follows.

1.5.1 Chapter 1: Introduction to the study

For the benefit of readers who may need to make use of this study's findings, but do not have the time to study the entire manuscript, Chapter 1 essays to provide a usable synopsis. It opens with a brief description of what the study set out to achieve, and a summary of its key results. It then proceeds to give a short description of each of the six chapters, as previously noted.

1.5.2 Chapter 2: Literature review and research questions

This chapter describes the literature reviewed as a basis of the research carried out in this study. It covers three general categories:

1) The meaning of the terms 'cognition' and 'cognitive' as used by human science researchers since the mid twentieth century;
2) The emergent meaning and measures of cognitive style; and
3) IS user satisfaction, its significance and measurement.

After a survey of scholarly literature in the areas of *cognition, cognitive theory* and *cognitive style*, the chapter explains why Kirton's A-I theory and its attendant instrument, the KAI were found to provide a suitable cognitive model and measure for the present study (see Chapter 2, Sections 2.2.4, 2.2.4.1 and Table 6).

The chapter then explores the significance and measure of user satisfaction in scholarly IS literature. In general, user satisfaction was found not to have developed into any workable theory which parallels cognitive theory. The chapter notes that inventors of user satisfaction instruments seldom underpin their attempts with managerial, psychological or sociological theory. Two deficits particularly significant to this study were demonstrated. First, little research was found which tried to relate user satisfaction to theories of motivation. Second, no previous instrument could be found which was able repeatedly to measure the same user's satisfaction with the same system at various points in time.

Finally, based on the discussion of the literature surveyed, the research questions as enumerated in Section 1.1 above are deduced. These are largely developed from speculation emerging from the literature, on how user satisfaction and user dissatisfaction would be expected to behave over time, especially in relation to the systems analyst-user cognitive differential.

1.5.3 Chapter 3: Development of hypotheses

As a preliminary, the research population is defined as user-systems or USs. Section 3.3 outlines the models which underpin the hypotheses. The hypotheses themselves are summarised at the end of Chapter 3 in Tables 16(a)-16(d). The chapter then discusses suitable instruments for the measurement of user satisfaction. It reaches the conclusion that a new measure is required, thereby providing a point of departure for the development and pilot-testing of the SSS. It investigates Herzberg's theory (see Appendix 2.7) and Mullany's R-Score (see Section 1.1) as possible bases (see Section 3.3.1). The chapter concludes that:

> ***The degree to which a user satisfier is unaddressed can be identified by the rated intensity of a complaint made by the user. The weighted sums of a user's complaints in respect of a system is a valid measure of overall dissatisfaction, and also of its reverse, overall satisfaction*** (see Section 3.3.1.3).

The credibility of the KAI to measure the cognitive style construct, is confirmed. General hypotheses emerging from A-I theory and its relation to user satisfaction are then discussed in Section 3.3.2.1.

Section 3.4 suggests that four simple mathematical trend models for the decline in the user's perceived severities of individual problems are possible candidates to fit the mean-severity data. Four associated hypotheses are then developed.

1.5.4 Chapter 4: The research methodology and design

The choice of the KAI instrument to measure cognitive style is confirmed in Section 4.3.1. The development of the SSS instrument is presented in a number of stages. First, merits, statistical and otherwise, of the R-Score are discussed and investigated (see Section 4.3.2). It notes the finding that the R-Score's reliability could be improved by adding a reversed, single-score measure of *satisfaction* to the R-Score. In Section 4.2.6 the Satisfaction Score (S-Score) is developed from the R-Score thus modified, by subtracting it from a constant of 40. This was further pilot-tested (see Section 4.3.7) to show that the validity of the S-Score, despite the lack of positive content, could be verified empirically. In Section 4.3.8, details of the construction of the physical SSS instrument are discussed. Particulars of the data collection procedure are given in Section 4.3.9, together with precautions taken. In Section 4.4 the methodology for the collection and analysis of the data is described.

1.5.5 Chapter 5: Results

This chapter discusses the outcomes and observations of the present study and their analysis. Section 5.2 covers a description of the data in somewhat more detail than given at the end of Section 1.1 above. The findings include tests of all the hypotheses identified in Chapter 3, using the data collected as described in Chapter 4. However, results beyond these were also found. A summary of the findings are given above in Section 1.4. Detailed lists of results are given in Chapter 5, Tables 27, 30, 33 and 34.

1.5.6 Chapter 6: Discussion and conclusion

This chapter begins by summarizing the study's contribution to knowledge (see Chapter 6, Section 6.2). The four research questions are revisited, together with the attendant results and emergent conclusions (for a summary of findings, see also Sections 1.4.1 to 1.4.5). Based on the first three of these, the four new rules for system development are deduced and justified (see Section 1.4.3 for a list of them). The best-fitting of the mean perceived severity curves are identified (see Section 1.4.4). Next, the chapter describes the "mechanical" model of motivation for systems usage and development (see Section 1.4.5). Two further outcomes of this study are discussed in Section 6.4: the construction and validation of the System Satisfaction Schedule (SSS) instrument and the use of Kirton's A-I theory and KAI in IS. These challenge some skeptical views on the value of cognitive style to IS for two regions of the system's life cycle: one in the first three months of usage and the other in the last three.

Section 6.5 suggests areas for further research, as follows:

- Replication of the present study as it stands (see Section 6.5.1);
- Further investigation of the rectilinear time-series model; (see Section 6.5.2);
- Validation of the impacts of the analyst/user cognitive gap generally over system usage life, and specifically in the two critical regions in the neighbourhoods of days 85 and 652 (see Section 6.5.3);
- Further validation of the SSS (see Section 6.5.4);
- Generalisation of this study's results to system development teams larger than the one user and one analyst cases investigated here (see Section 6.5.5);
- Further investigation of the proposed new "mechanical" model (see Section 6.5.6);
- Further investigation into the trends of perceived problem severities (see Section 6.5.7); and
- The contribution of user satisfaction to system success (see Section 6.5.8).

1.6 Summary of Chapter 1

This chapter has outlined the nature of the empirical study (see Section 1.1) and then enumerated its key findings in summarized form (see Section 1.4). Thereafter it has given a brief synopsis of the material covered in each chapter (see Sections 1.5.1 to 1.5.6). Hopefully this will act as an efficient guide to readers who only require a limited overall view of the study, and/or only certain parts of it in depth.

Chapter 2

Literature review and research questions

2.1 Introduction

Since this study essayed to examine the impact of the user-analyst cognitive style differential on user satisfaction during information system usage, the fundamental terms *system*, *user* and *analyst* needed clarification. A *system*, or computer-based system is taken to mean, an

> "organized combination of people, hardware, software, communication networks and data resources" (O'Brien, 2003).

This definition includes all such systems irrespective of platform or technology. It thus includes, for example, systems written in a third generation language such as COBOL, those based on common, off-the-shelf (COTS) packages, and those generated using the .net platform.

A *user* is taken to mean anyone who uses one or more computer-based systems. Doll and Torkzadeh (1988) suggest that certain types of systems no longer require direct user interaction with an IS person, so they introduced the notion of *end user* as users of this category (see Section 2.3.1). However, observations made during data collection over the period 2004 - 2005, suggest that there is no shortage of new systems in which an IS person developed the system in collaboration with a user. In other words, end users have certainly not replaced the more traditional type of user. Insofar, then, as a system development effort may involve the analytical and/or developmental phases of system generation, this study found the term "developer" to be a synonym for "analyst" previously used in, for example, Mullany's (1989) study. The definition of an *analyst* or *systems analyst* in the present study was thus taken to be:

> ***a person whom the user identified unequivocally as the one who had guided them through the system development effort, whom they turned to for help and who had in all cases undertaken the technical tasks associated with the system-building and maintenance.***

This gave rise to a precaution during the data collection process; that if the same analyst ceased to be involved in the target system, no further data was collected from the user in respect of that system (see Chapter 4, Section 4.2, property 2, and Section 4.3.9).

As mentioned above, the aim of this study was to examine the impact of the user-analyst cognitive style differential on user satisfaction during information system usage. In Chapter 1, Section 1.1.1, it was noted that the present study examined system usage; not system development. However, as there explained, development and usage are usually intertwined by way of early or on-going maintenance. Hence the analyst may interact with the user via the system (s)he developed and in person during system maintenance. These interactions may give rise to the effect of their similar or dissimilar cognitive styles, since the analyst's system, and hence solutions to problems, are imposed upon the user on an ongoing basis (Mullany, 1989).

As outlined in Chapter 1, this study was motivated by the following:

- Mullany's (1989) study, which used Kirton's (1976) KAI instrument to measure cognitive style, and which showed that the difference in scores between users and analysts is positively associated with the number and intensity of user complaints (Kirton, 1999). This study, however, used a modest sample size of 34 instances of users in conjunction with their systems. Though users were distributed over 16 systems in 10 large national or multi-national organizations in South Africa, only one reading per incidence of a user and an associated system was taken. It thus did not contribute any knowledge as to how user's complaints might vary over time, and whether or not this had happened according to any predictable pattern or principle.
- The development of a theory which enables cognitive style measures to predict user satisfaction.

The survey of the literature revealed two gaps:

1. It found no recent enquiries into the relationship between user satisfaction and the cognitive styles of those participating in system development; and
2. The patterns and principles inherent in the changes in user satisfaction over system usage time were underrepresented.

Scholarly literature exists which identifies user satisfaction as a key element of system success (see Table 8). This study makes no claim that user satisfaction and system success are identical. However, as scholarly opinion exists that user satisfaction contributes to system success, this study contributes to the knowledge of how to develop successful systems.

In the light of the above, three categories of literature were surveyed:

- The meaning of the terms ‘cognition’ and ‘cognitive’ as used by human science researchers since the mid twentieth century;
- The emergent meaning and measures of cognitive style; and
- IS user satisfaction, its significance and measurement.

This chapter first discusses the literature in the general areas of *cognition* and *cognitive theory* and the emergent constructs and measures of *cognitive style*.

Next, the chapter examines the significance and measure of user satisfaction in the relevant IS literature. Of all the factor-based instruments found in the IS literature since 1980, only two receive significant mention. They are: Pearson’s 39-factor instrument and Olsen, Ives and Baroudi’s User Information Satisfaction short-form. These are described and discussed as typical of this class of instrument.

Finally, based on the discussion of the literature surveyed, this chapter raises new research questions, which formed the basis of the present study. Where this chapter uses the adjective *scholarly* to describe, for example, research and/or literature, it implies sources which are significantly cited by university academics, postgraduate scholars and professional researchers.

2.2 Cognition and cognitive theory

This section examines the origins of the term *cognitive* in psychological research as a means for understanding the emergent concept of *cognitive style*. This aim necessitated a discussion of a number of historic studies to show how *cognitive psychology* originated and how it has changed. The word *cognition* comes from the Latin *cognitio*, meaning *I apprehend*, or translated more freely, *I pick up*.

2.2.1 The emergence of the notion of *cognitive construct* and related theories

These theories propose that individuals not only acquire knowledge, but mentally order and classify knowledge. For example, Vygotsky (early twentieth century; in Daniels, 1996) in a discussion of his theory of *Constructivism*, applied the term *construct* to how individuals 'construct' material they are learning 'inside their heads' (Atherton, 2003). In general, cognition as a field of study became an enquiry into how individuals acquire knowledge, how they retain it, how they mentally structure it and how they use it. This has obvious implications for the fields of education, learning and training. It has less obvious implications for managers and team dynamics, where an effort may be made to get a group of individuals to agree on solutions to problems. This later led to organisational research, which focuses more on the cognitive attributes of employees, and which could lead to a better understanding of how work groups should be selected and managed (Kirton, 2003). Vygotsky identifies "cognitive constructivism" which denotes individual learning and understanding, and "social constructivism", which is about how meanings and understandings grow out of social interaction.

Though introducing basic concepts in cognitive psychology such as that of the *cognitive construct* Vygotsky produced theories, some of which were difficult to test empirically. By contrast the next cognitive theorist of significance, Kelly (1955), formalised and refined such prior theories, and produced his *Personal Construct Theory* with his concept of the *personal construct* or *cognitive structure*. Atherton (2003) describes Kelly's work as a "complete psychology", explicit about its assumptions and theoretical base. In other words, it invites comparison with the physical sciences for academic rigour. It thus remains a reliable theory, fundamental to any discussion involving things cognitive. It was almost certainly the forerunner of the notion of *cognitive style*; a term which his theory uses to denote classifications of individuals' *cognitive structures*. He abandons the notion of learning in favour of a theory of how individuals make sense of the world, and how this changes with time. Basic to this theory is the postulate that personal identity is defined by the way an individual *construes* or "understands" his/her personal worlds. Kelly thus established the "cognitive approach" in psychological research which evidently goes beyond the classical distinctions between cognition, emotion and conation ("will") found in other psychologies (Kelly, 1955). Cognitive structure, he describes as a comparison between an individual's *cognitive complexity* and *cognitive simplicity*. *Cognitive complexity* denotes an individual's ability to perceive differences in the way in which he/she perceives (construes) other people's personalities. *Cognitive simplicity*, on the other hand, is the ability to group them into classes so that generalisations can be made about members of each class.

Kelly also produced the first generally used measure of cognitive structure, known as the *Repertory Grid*, or *RepGrid*. One may consider, for instance, the task of measuring an employee's reaction to the management of his organization as it affects him. The employee is first invited to identify some managers whom he regards as key to his management environment. These form what Kelly calls the *elements* of the instrument; that is, those key people or things which the respondent associates with his/her prevailing work situation. Next the respondent is asked to identify those qualities (called *constructs*), which most distinguishes one element from another. This is rated using all combinations of three elements from the list identified. The constructs are established in terms of which quality distinguishes two of them from the third. For example, in one group of three, two managers may be formal while the other one is informal. The grid instrument is then constructed as shown in Table 1(a).

Table 1(a): Sample Repertory Grid: Rating Of Managers

Similarity or Emergent Pole	**Elements**						**Contrast Pole**
	Manager A	**Manager B**	**Manager C**	**Manager D**	**Manager E**	**Manager F**	
Informal							Formal
Knowledgeable							Ignorant
Democratic							Autocratic
Pleasant							Unpleasant
etc.							

Next the respondent is asked to rate each element on a Likert-type scale. If a five-point scale were used, for example, the lowest rating of 1 would apply to the extreme of the similarity pole and, of course, 5 to the most extreme in the contrasting antipode. Please refer to Table 1(b) for an example.

Table 1(b): Sample Repertory Grid: Rating Of The Management

Similarity or Emergent Pole	Elements						Contrast Pole
	Manager A	**Manager B**	**Manager C**	**Manager D**	**Manager E**	**Manager F**	
Informal	1	5	4	3	4	3	Formal
Knowledgeable	1	2	4	3	5	1	Ignorant
Democratic	1	2	2	3	2	1	Autocratic
Pleasant	1	1	1	1	5	2	Unpleasant
etc.							

The analysis of the data so collected may involve factor analysis or analysis of variance. The instrument may be applied either to individuals or groups, or to group-chosen elements rated by individuals in the group.

The strength of this evaluation technique is that it assumes that a respondent's knowledge is a *constructed version of the world*, and thus uses the respondent's ratings of the elements which they themselves have chosen as the key to a given situation. A particular such version of the world and its evaluation represents a person's *cognitive style.*

Tan and Hunter (2002) in a literature survey of IS studies note the potential for use of Kelly's RepGrid at present and showed that some researchers in scholarly IS research are currently making use of this instrument. They therefore suggest that its use is still valuable for the diagnosis of and intervention in systems problems at both the individual and organizational levels. Kirton (1999) makes substantial use of Kelly's definitions of cognitive structure in a description of his much more recently formulated A-I theory (see Section 2.2.4) hence the RepGrid was found to be an instrument which remains usable in occupational studies, including the field of IS.

Out of Kelly's theory, later researchers developed the concept of *cognitive dissonance*. Festinger (1957), for example, who observed that people who fail to learn when expected to learn, usually suffer a degree of *mental anxiety*. This, he termed *cognitive dissonance*. Failure to learn, he suggests, is owing to a lack of readiness to learn. This lack of readiness, he put down to the discomfort felt as a discrepancy between what the individual already knows or believes, and new information or interpretation. It occurs when there is a need to *accommodate* new ideas, so the individual needs to develop to become "open" to them. Of significance is the notion that an individual, while attempting to learn, will either experience a positive or negative learning experience and in consequence, either a successful or unsuccessful outcome. This suggests that there is something essentially dichotomous about learning situations in relation to an individual and his/her learning environment.

2.2.1.1 Critique of early cognitive construct theories

These theories developed the idea of ***construct***. This gave a term for the process of mental reception, perception and knowledge-processing (Vygotsky in Daniels, 1996). They also demonstrated the impact of the ***learning environment*** on the learning process, including cognitive dissonance: the mental anxiety suffered by people who fail to learn when expected to learn. They also suggest a ***dichotomy*** of ***learning situations*** in relation to an individual and his/her learning environment; those in which learning does occur, and those in which it does not (Vygotsky in Daniels (1996), and Festinger (1957)). A means of measuring cognitive structure, namely the ***Repertory Grid*** emerged (Kelly, 1955). This is still in use by scholars today (Tan and Hunter, 2002, and Kirton, 1999). Furthermore, scientific rigor was successfully applied by Kelly (1955) to psychological research in the development of his ***Personal Construct Theory.*** This means that cognitive studies may invite comparison with the rigour of research in the physical sciences (Atherton, 2003) and so promote the image of psychology as a science.

By contrast, however, these theories generally ignore the impact of ***cognitive ability*** as separate from ***cognitive style***. For instance, Festinger (1957) put down an inability to learn to a discrepancy between what the individual already knows or believes, and new information or interpretation. There is no real suggestion that a person's failure to learn may just be an *inability* to learn. In short, these theories leave the concept of cognitive structure as some indeterminable mix of style and level. This problem has persisted in cognitive style measurements up to the present time; for example, in the case of the well-known Myers-Briggs Type Indicator (MBTI), there remains some doubt as to whether the scales proposed measure style independent of level (see Section 2.2.2.1 and Kirton, 2003).

Only one key method of measurement emerged from the scholarly literature, namely, the ***Repertory Grid***. This does not stipulate universal scales for the bipolar ratings. Hence there is a limitation when comparisons between studies are required, as the numeric ranges could differ from study to study. Furthermore, neither the RepGrid nor any of the theory described above has much power directly to ***predict*** the effects of putting people together in a work group. Measurements are made once individuals are already in an occupational situation. Typically these theories content themselves with describing existing situations as they *have* unfolded rather than developing new rules for precipitating desirable *future* outcomes: for instance, in team selection (IS or otherwise).

2.2.2 The development of multi-descriptor views of 'cognitive style'

The term "cognitive style" remains in significant use in current literature and several recent articles propose definitions for it. For example, Liu and Ginther (2002) define *cognitive style* as,

> "An individual's consistent and characteristic predispositions of perceiving, remembering, organizing, processing, thinking and problem-solving."

Schroder, Driver and Streufert (1967), in a discussion of human information processing, state that organisms

> "either inherit or develop characteristic modes of thinking, adapting or responding and go on to focus upon adaptation in terms of information processing".

Kirton (2003) defines cognitive style as

> "a *stable*, *preferred* manner in which an individual brings about change".

In short, a person's cognitive style can be expressed as a number of descriptions of their personality. Table 2 gives a selection of empirical studies using a measure of so-called "cognitive style" from 1976 to the present. This table exhibits 76 key studies of which 38 (50%) used the KAI exclusively while 36 (47%) used other instruments. 2 (3%) used both the KAI and another instrument. Only 5 (7%) made use of the MBTI. Across the entire study, only 7 (9%) used IS staff samples.

Table 2: 'Cognitive Style' constructs: empirical studies from 1976 to the present
(Table occupies pages 45 to 50)

Year	Study	Research Area	Literature Source	Sample	Measure/construct claimed
1976	Kirton	Psychology, applied psychology	Journal of Applied Psychology	286 respondents from general UK population	Cognitive style, using the KAI
1978	Keller & Holland	Psychology, applied psychology	Journal of Applied Psychology	256 professionals in 3 applied R&D departments	Cognitive style, using the KAI
1980	Mulligan & Martin	Psychology, applied psychology	Psychological Reports	303 high school students, age: c. 17 years	Cognitive style, using the KAI
1981	Kirton	Psychology, applied psychology	Journal of Personality Assessment	355 subjects + replication sample of 276	Cognitive style, using the KAI
1983	Sims, Graves, & Simpson	Management, organisational, administrative	Journal of Occupational Psychology	145 UK miners	Cognitive style, using the GEFT
1984	Goldsmith	Psychology, applied psychology	Journal of Psychology	106 (54 male and 52 female) undergraduates	Cognitive style, using the AI
1985	Goldsmith	Psychology, applied psychology	Journal of Psychology	94 (44 male and 50 female) undergraduates	Cognitive style, using the KAI
1986	Foxal & Haskins,	Marketing	European Journal of Marketing	101 women shopping in a medium-size UK town	Cognitive style, using the KAI
1986	Foxall	Management, organisational, administrative	Technovation	115 MBA students + 31 sponsored students, 1 business school	Cognitive style, using the KAI
1986	Foxall	Management, organisational, administrative	Journal of Managerial Psychology	115 mid-career managers attending a MBA program, 1 UK business school	Cognitive style, using the KAI
1986	Foxall	Management, organisational, administrative	Technovation	146 Managers in re-training:115 MBA students + 31 sponsored students	Cognitive style, using the KAI
1986	Goldsmith	Marketing	Journal of Social Psychology	260 Grocery shoppers, divided into suspect group (103) + regular group (157)	Cognitive style, using the KAI
1986	Goldsmith & Matherly	Psychology, applied psychology	Journal of Psychology	171 American college students	Cognitive style, using the KAI
1986	Goldsmith (Study 1)	Psychology, applied psychology	Educational and Psychological Measurement	98 (50 male & 48 female) undergraduates	Cognitive style, using the KAI
1986	Goldsmith (Study 2)	Psychology, applied psychology	Educational and Psychological Measurement	93 (44 male & 49 female) undergraduates	Cognitive style, using the KAI

Table 2: 'Cognitive Style' constructs: empirical studies from 1976 to the present

Continued from page 45

(Table occupies pages 45 to 50)

Year	Study	Research Area	Literature Source	Sample	Measure/construct claimed
1986	Goldsmith, Matherly & Wheatley	Education, educational psychology, training	Educational and Psychological Measurement	89 American undergraduates	Cognitive style, using the KAI
1986	Gul	Education, educational psychology, training	Journal of Accounting Education	33 final-year accounting students, 1 University	Cognitive style, using the KAI
1986	Hammond	Psychology, applied psychology	Personality and Individual Differences	374 (166 male, 208 female) secondary school students	Cognitive style, using the KAI
1986	Kirton & De Ciantis	Psychology, applied psychology	Personality and Individual Differences	83 professional staff, 2 companies	Cognitive style, using the KAI and Cattell's 16PF
1987	De Ciantis	Psychology, applied psychology	Ph.D. Thesis, University of Hertfordshire	203 UK managers	Cognitive style, using the KAI
1988	Beene & Zelhart	Psychology, applied psychology	Perceptual and Motor Skills	289 USA undergraduates	Cognitive style, using the KAI
1989	Mullany	Information systems	Master's Thesis, Department of Accounting, University of Cape Town	34 users, 10 organisations	Cognitive style, using the KAI
1990	Rickards	Psychology, applied psychology	Journal of European Industrial Training	A team of researchers attending a 3-day training workshop	Cognitive style, using the KAI
1991	Foxall & Bhate	Information systems	Technovation	107 computer users, who were graduate students	Cognitive style, using the KAI
1991	Goldsmith & Kerr,	Management, organisational, administrative	Technovation	34 entrepreneurship students + control group of 24 other students	Cognitive style, using the KAI
1991	Kirton, Bailey, & Glendinning	Education, educational psychology, training	Journal of Psychology	182 British school teachers	Cognitive style, using the KAI
1991	Prato Previde	Psychology, applied psychology	Personality and Individual Differences	835 from general Italian population	Cognitive style, using the KAI
1992	Kubes	Psychology, applied psychology	Psychology: International Journal of Human Behaviour	353 respondents from general Slovak/Czech populations	Cognitive style, using the KAI
1992	Riding & Sadler-Smith	Education, educational psychology, training	Educational Studies	129 students, ages: 14- 19 years	Cognitive style, using the CSA
1993	Buttner & Gryskiewicz	Management, organisational, administrative	Journal of Small Business Management	101 women, shopping in a medium-size UK town	Cognitive style, using the KAI
1993	Clapp	Psychology, applied psychology	Psychological Reports	153 workers in the UK	Cognitive style, using the KAI

Table 2: 'Cognitive Style' constructs: empirical studies from 1976 to the present

Continued from page 46

(Table occupies pages 45 to 50)

Year	Study	Research Area	Literature Source	Sample	Measure/construct claimed
1993	Foxall & Bhate	Marketing	Journal of Economic Psychology	151 female food consumers recruited as they left supermarkets in southeast England	Cognitive style, using the KAI
1994	Claxton & Mcintyre	Marketing	Psychological Reports	69 female and 98 male undergraduate students, 1 business school	Cognitive style, using the MBTI
1994	Riding & Pearson	Education, educational psychology, training	Educational Psychology	119 middle school pupils, 63 males and 56 females, ages:12-13 years	Cognitive style, using the CSA
1995	Bagozzi & Foxall,	Psychology, applied psychology	European Journal of Personality	3 samples of postgraduate students: UK, 149, Australia, 142, USA131	Cognitive style, using the KAI
1995	Chan	Auditing	Managerial Auditing Journal	20 auditors, 4 audit firms	Cognitive style, using the GEFT
1996	Patel & Day	Education, educational psychology, training	The British Accounting Review	191 students at 1 University	Cognitive style, using the GEFT
1996	Riding & Read	Education, educational psychology, training	Educational Psychology	78 pupils, from 4 secondary comprehensive schools, age: 12-years	Cognitive style, using the CSA
1997	Riding & Agrell	Education, educational psychology, training	Educational Studies	205 school pupils, 99 females and 106 males, ages: 14-16 years, over 2 schools	Cognitive style, using the CSA
1997	Riding & Watts	Education, educational psychology, training	Educational Psychology	90 female pupils from 1 single-sex secondary grammar school, ages: 15-16 years	Cognitive style, using the CSA
1997	Riding & Wigley	Education, educational psychology, training	Personality and Individual Differences	340 further education students, ages: 16–18 years	Cognitive style, using the CSA
1997	Tullett & Davies	Psychology, applied psychology	Personality and Individual Differences	105 UK multiple projects managers + 109 UK R&D Managers (also used 114 Slovak R&D Managers from a prior study)	Cognitive style, using the KAI

Table 2: ‘Cognitive Style’ constructs: empirical studies from 1976 to the present

Continued from page 47

(Table occupies pages 45 to 50)

Year	Study	Research Area	Literature Source	Sample	Measure/construct claimed
1998	Janssen, De Vries & Cozijnsen (Study 1)	Psychology, applied psychology	Human Relations	15 first-line managers and 61 constables, 1 police district	Cognitive style, using the KAI
1998	Janssen, De Vries & Cozijnsen (Study 2)	Psychology, applied psychology	Human Relations	4 first-line managers and 77 constables, 1 police district	Cognitive style, using the KAI
1998	Riding & Al-Sanabani	Education, educational psychology, training	International journal of Educational Research	200 students from a school in the UK for children from a Yemeni background, ages: 10–15 years	Cognitive style, using the CSA
1999	Bobic, Davis & Cunningham	Management, organisational, administrative	Review of Public Personnel Administration	203 mid-level managers, 122 international managers and 262 students	Cognitive style, using the KAI
1999	Riding & Grimley	Education, educational psychology, training	British Journal of Educational Technology	80 students, 40 males and 40 females, age: 11 years, from an urban primary school	Cognitive style, using the CSA
1999	Sadler-Smith	Management, organisational, administrative	Journal of Managerial Psychology	226 undergraduates, 1 business sch, in a university	Cognitive style, using the CSI
1999	Sadler-Smith & Riding	Education, educational psychology, training	Instructional Science	240 business studies students at a UK university	Cognitive style, using the CSA
2000	Allinson & Hayes	Management, organisational, administrative	International Journal of Human Resource Management	394 managers from six nations and 360 management students from five nations	Cognitive style, using the CSI
2000	Allinson, Chell and Hayes	Management, organisational, administrative	European Journal of Work and Organizational Psychology	156 founders of high growth companies and 546 managers	Cognitive style, using the CSI
2000	Chan	Management, organisational, administrative	Multivariate Behavioral Research	773 civil service employees	Cognitive style, using the KAI
2000	Hill, Puurula, Sitko-Lutek, Rakowska	Education, educational psychology	Educational Psychology	200 managers in Finland, Poland and the UK	Cognitive style, using the CSI
2000	Priddey & Williams	Management, organisational, administrative	Personnel Review	14 Finance managers + 12 Defence sector managers	Cognitive style, using the KAI

Table 2: 'Cognitive Style' constructs: empirical studies from 1976 to the present

Continued from page 48

(Table occupies pages 45 to 50)

Year	Study	Research Area	Literature Source	Sample	Measure/construct claimed
2000	Ramsay, Hanlon & Smith	Education, educational psychology, training	Journal of Accounting Education	132 students, 1 university	Cognitive style, using the MBTI
2000	Rothman	Management, organisational, administrative	International Journal of Management	278 managers from different cultural roots	Cognitive style, using the EFT
2000	Sadler-Smith, Allinson & Hayes	Management, organisational, administrative	Management Learning	127 personnel practitioners, 1 country, UK	Cognitive style, using the CSI
2001	Allinson, Armstrong and Hayes	Management, organisational, administrative	Journal of Occupational and Organizational Psychology	142 manager-subordinate dyads in two large manufacturing organizations	Cognitive style, using the CSI
2001	Armstrong	Education, educational psychology, training	Educational Psychology	412 final year undergraduate degree students, 1 university	Cognitive style, using the CSI
2001	Ford, Miller & Moss	Information systems	Journal of the American Society for Information Science and Technology	69 Masters students, I university	Cognitive style, using the CSA
2001	Littlemore	Language, linguistics	Applied Linguistics	82 French-speaking students taking English, 1 university	Cognitive style, using the CSA
2001	Lu, Yu & Lu	Information systems	European Journal of Operational Research	108 senior students in two MIS courses at 1 university	Cognitive style, using the MBTI
2002	Buffinton, Jablokow & Martin	Management, organisational, administrative	Engineering Management Journal	20 students, 1 institute of 1 University	Cognitive style, using the KAI
2002	Millward & Freeman, Study 1	Management, organisational, administrative	Creativity Research Journal	55 managers, (33 Women, + 44 men)	Cognitive style, using the KAI (using 19-point instead of 5-point scales)
2002	Millward & Freeman, Study 2	Management, organisational, administrative	Creativity Research Journal	20 persons, 10 managers (5 male, 5 female) + 10 nonmanagers (5 male, 5 female).	Cognitive style, using the KAI (using 19-point instead of 5-point scales)
2002	Monavvarrian	Management, organisational, administrative	Public Organization Review	174 Iranian reform agents, (32 female, 142 male), 8 top managers, 58 middle-managers, 8 low-level managers, 96 non-managers	Cognitive style, using the KAI, slightly modified wording for scales
2003	Cheng, Luckett & Schulz	Psychology, applied psychology	Behavioral Research in Accounting	271 students	Cognitive style, using the MBTI

Table 2: 'Cognitive Style' constructs: empirical studies from 1976 to the present

Continued from page 49

(Table occupies pages 45 to 50)

Year	Study	Research Area	Literature Source	Sample	Measure/construct claimed
2003	Gallivan	Information systems	Information & Management	220 analysts in two firms	Cognitive style, using the KAI
2003	Hodgkinson & Sadler-Smith	Psychology, applied psychology	Journal of Occupational and Organizational Psychology	501 respondents	Cognitive style, using the CSI and the MBTI
2003	Huang	Information systems	Information & Management	40 management professionals, multiple sites	Cognitive style, using the GEFT
2003	Isaksen, Lauer & Wilson	Psychology, applied psychology	Creativity Research Journal	1483 individuals from both education and business settings	Cognitive style, using the KAI and the MBTI
2004	Alevriadou, Hatzinikolaou, Tsakiridou & Grouios	Psychology, applied psychology	Perceptual and Motor Skills	96 retarded boys subdivided into four groups	Cognitive style, using the GEFT
2004	Hayes J.; Allinson C.W.; Armstrong S.J.	Management, organisational, administrative	Personnel Review	3 UK samples of managers, 3 UK samples of non-managers.	Cognitive style, using the CSI
2004	Hite	Education, educational psychology, training	Reading Research and Instruction	90 university juniors & seniors, 1 university	Cognitive style, using the GEFT
2004	Chen, Magoulas & Dimakopoulos	Information systems	Journal of the American Society for Information Science and Technology	17 end-users	Cognitive style, using Riding's CSA
2005	Hough & Ogilvie	Management, organisational, administrative	Journal of Management Studies	749 managers attending executive training programmes	Cognitive style, using the MBTI

One of the best known of the multi descriptor measures of cognitive style is the Myers-Briggs Type Indicator (MBTI). According to Carey (1991) this was the most frequently used in MIS/DSS research up to 1990. A review of research literature on the MBTI from 1960 to the present suggests the same. However, as is evident from Table 2, only five of the 76 cognitive style studies found since 1976 did so.

Skehan (2000), describes the MBTI as having four scales, namely:

- E – I (Extraversion – Introversion)
- S – N (Sensing – iNtuitive)
- T – F (Thinking – Feeling)
- J – P (Judging attitude – Perceiving attitude),

where the various scale extremes denote personality traits as follows:

- E: Extraversion (focuses attention on the outer world of people and things);
- I: Introversion (focuses on the inner world of thoughts and ideas);
- S: Sensing (detailed, concerned with parts, lives in present, factual);
- N: Intuition (lives in future, generalist, hypothetical, idealistic;
- T: Thinking (logical, analytical, impersonal and theoretical);
- F: Feeling (warm, personal, concerned with people's feelings, good communication skills);
- J: Judging attitude (takes primarily a judging attitude using thinking or feeling);

and

- P: Perceiving attitude (using sensing or intuition towards the world).

Sixteen broad personality types are thus obtainable since the above eight traits, distributed as pairs over the four scales, yield sixteen combinations.

A more recent multi-descriptor instrument was devised by Riding (1991). This is a two-dimensional cognitive style instrument, his Cognitive Style Analysis (CSA), which is a computer-based test. This enables response times to be measured as a way of rating the subjects' relative efficiencies in performing two categories of mental task. Consisting of three sub-tests, it attempts to measure both ends of the so-called "Wholist-Analytic" and "Verbal-Imagery" dimensions. The first test purports to measure the "Verbal-Imagery" dimension. It displays statements one at a time to the respondent each of which (s)he is asked to rate as "true" or "false".

Hence half of the statements contain information about conceptual categories and only half of these are true. The assumption is that imagers will respond more readily to the appearance statements, because they can readily form mental pictures. On the other hand, verbalisers should exhibit a shorter response time for the conceptual statements because these cannot be represented in visual form. The computer system records the response times and calculates a so-called "Verbal-Imagery" Ratio. A low ratio corresponds to a "Verbaliser" and a high ratio to an "Imager". A mid-scorer is rated as "Bimodal". As the respondents have to read both the verbal and the imagery items, reading ability and reading speed are claimed to be taken into account (Riding and Cheema, 1991).

The second "Wholist-Analytic" dimension is measured by the second and third sub-tests. The second sub-test contains pairs of complex geometrical figures which the respondent is asked to judge as either the same or different. Wholists are expected to respond quickly on this test as it requires judgment on the overall similarity of the figures in each pair. The third test is similar except that it asks for judgments as to whether simple figures are contained in their more complex partners. This task requires a degree of "disembedding" of each simple shape from its complex partner, so in theory "Analytics" should be quicker at this. The system records the response times, and calculates the "Wholist/Analytic" Ratio. A low ratio corresponds to a "Wholist" and a high ratio to an "Analytic". Mid-scorers are rated as "Intermediate" (Riding and Cheema, 1991). According to Riding et al. (1991), each of these dimensions is a continuum, independent of the other.

2.2.2.1 Critique of the multi-descriptor measures of cognitive style

In an attempt to validate the MBTI, Harrington and Loffredo (2001) conducted an empirical study using 97 college students, 79 of whom were women. All the participants were asked to complete four instruments: the Psychological Well-Being Inventory (Ryff), the Satisfaction With Life Scale (Diener, Emmons, Larsen, Griffin), the Self-Consciousness Scale-Revised (Scheier and Carver), and the MBTI

(Form G Self-Scoring) (for the sources, see Harrington and Loffredo, 2001). They found significant differences on three of the four scales of the MBTI with extraverts showing higher 'psychological well-being' and 'life satisfaction', and lower 'self-consciousness' than introverts. Also, in their sample, 'intuition types' scored higher in 'psychological well-being' and lower in 'self-consciousness' than did the Sensing types. 'Judging types' scored higher in psychological well-being than 'Perceiving types'. While these results suggest the construct validity of the MBTI, one should note that the majority of the participants were white women and all were college students, thus making it unclear as to whether or not the results can be generalised to the world population, or more specifically to the world of IS participants.

Skehan (2000) claims, in agreement with one finding of the present study, that the MBTI is the 'most widely used of any personality indicator' of cognitive style. He also draws attention to the prolonged time (thirty-five years) during which the instrument has been rigorously tried and evaluated. From the point of view of types of analysis that look for correlations between single scale measurements, this instrument suffers from the limitation that it measures cognitive style as a composite of four not necessarily compatible dimensions. The output tends to be a multi-descriptor expression of personality rather than something that is amenable to association or correlation determination. Carne and Kirton (1982) in an empirical study found that the four dimensions can be combined into fewer for the calculation of correlations with, for example, a measure of user satisfaction. Kirton (2004) further suggests that the MBTI scales really measure a mix of cognitive style and level, not just of style: a limitation already discussed in the previous section. In any case, the MBTI overall is not as suited as a single-scale instrument to the determination of associations and correlations with other factors, such as user satisfaction; a difficulty from the point of view of this study.

Riding's (1991) CSA is claimed to measure two dimensions of cognitive style, namely "Wholist-Analytic" and "Verbal-Imagery". These are continua, so if one is looking for a means of predicting some dependent variable, such as user satisfaction, one or other of these scales at first seems satisfactory. Additionally, parallels can be seen between the two CSA scales and several other bipolar measures (see Sections 2.2.2 and 2.2.3). For example, the Wholist-Analytic scale is not far removed from Pask's

Holist-Serialist classification, while the Verbal-Imagery scale is similar to Witkin's field-dependence-independence measure (see Section 2.2.3 below for comparisons). Indeed, the second of Riding's tests (see Section 2.2.2) is similar in style to Witkin's Embedded Figures Test (EFT) (see Section 2.2.3). These similarities support the construct validity of the CSA. Following such arguments, Sadler-Smith, Spicer and Tsang (2000), using a sample of 1,050 managers and professionals, attempted to validate the "Wholist-Analytic" scale of the CSA against the Allinson-Hayes Cognitive Style Index (CSI) (see Section 2.2.3). They failed to find any significant correlations or effects. The same study, however, showed that the CSI items are homogeneous and exhibit high reliability over a diverse sample range. These observations support the construct validity of the CSI while at the same time casting doubt on the construct validity of one of the CSA's dimensions.

Parkinson, Mullally and Redmond (2004), in an attempt to measure the reliability of the CSA, conducted two empirical evaluations of the test-retest reliability of the CSA. In their first study, 51 students (mainly third year) from the disciplines of computer science (mostly), engineering and some other disciplines including arts (but none from psychology) took part. They completed the CSA twice, at an interval of 14 days. In the second study, a different group of 96 (third year) information systems students participated on the first occasion. Approximately twenty three months later 27 of these students completed the CSA again in evidently near-identical conditions. They found the test–retest reliability, measured using the Pearson product-moment correlation for groups of largely third year information systems and engineering students to give an average of $r = 0.34$ for the wholist-analytic dimension while the verbaliser–imager dimension varied between -0.19 and 0.36. As these values are considerably below what they call

> "the generally accepted value of $r = 0.8$"

they concluded that the CSA does not estimate the Wholist-Analyst and Verbal-Imagery dimensions with sufficient precision for at least their samples. They further deduced from these results that the Wholist-Analyst dimension is stable but low whereas the Verbal-Imagery dimension by contrast is quite erratic. This unreliability, together with the findings of Saddler-Smith et al. (2000, see above), led the current study not to consider the CSA further as a viable instrument to measure cognitive style.

2.2.3 The development of continuous, bipolar measures of 'cognitive style'

A differing approach to measuring the cognitive attributes of people, which does not have the empirical limitations associated with the multi-descriptor approach of the MBTI, were attempts to construct continuous, bipolar measures for what were loosely called 'cognitive style'. These typically identify two "extremes" of so-called "cognitive style" and a scale on which people can be rated, between the two. The Witkin field dependence-independence model, for example, identifies an individual's perceptive behaviour while distinguishing *object figures* from the *content field* in which they are set (Witkin, Goodenough and Karp, 1967). Two similar instruments to do this were produced, the Embedded Figures Test (EFT) (Witkin, et al., 1967) and the Group Embedded Figures Test (GEFT) (Oltman, Raskin, and Witkin, 1971). In both cases, the content field is a distracting or confusing background. According to Witkin, these instruments distinguish *field-independent* from *field-dependent* cognitive types; a rating which he claims to be value-neutral. Field-independent people, he suggests, tend to be more autonomous when it comes to the development of *restructuring skills*; that is, those skills required during technical tasks with which the individual is not necessarily familiar. They are, however, less autonomous in the development of *interpersonal* skills. Field-dependent persons, he intimates, are the reverse. Furthermore, according to Witkin, Moore, Goodenough and Cox (1977), field-independent persons tend to be inherently self-motivated and to enjoy self-selected learning, while field-dependent persons need to be externally motivated and prefer joint-learning in groups.

Antonietti and Gioletta (1995) found that field-independent persons are more likely to be analogical problem solvers (solving problems using analogies from previous experience) than field-dependent persons. Additionally, Braune and Wickens (1986) found that field-independent persons are better at *parallel processing* (dealing with more than one problem at once) than are field-dependant persons. The latter are better at *serial processing* than their antipode.

Witkin's Field dependence-independence model and the associated EFT and GEFT continue to enjoy support and usage in the research literature. For example, Taggart and Robey (1981) published a discussion of a

> "conceptual framework … that integrates several trains of thought, including neurological studies in medicine, the psychological typology of Jung, and philosophical explanations of duality".

However, in a discussion of the use of the EFT in MIS/DSS research, they found that it yielded inconsistent results. Robey (1992) levels the same criticism at most other single-scale measures of cognitive style. In a survey of IS research over the previous fifty-years, Banker and Kauffman (2004) mention issues relating to both cognitive style and cognitive process. However, they do not mention any IS research which made recent use of the EFT or the GEFT.

Another theorist taking the bipolar approach was Hudson (1967). In a study of English schoolboys, he found that "accepted" measures of intelligence such as IQ or conventional scholastic assessments did not always predict their abilities. Conventional assessments, he argued, while giving credit for so-called "right" answers, under-estimated creativity and unconventional approaches to problem-solving. He identified two different *styles* of thinking and ability among them: *convergent* thinkers, good at accumulating material from a variety of sources relevant to a problem's solution, and *divergent* thinkers who proceed more creatively and subjectively in their approach to problem-solving. Convergent thinking is, he claims, particularly appropriate in subjects such as mathematics and the exact sciences. Divergent thinking, on the other hand, is more appropriate in creative and humanitarian disciplines, where usually no single proven answer exists. As convergent thinking is the basis for IQ tests and several other types of assessment, creativity is given little credit. Hudson (1967) distinguished between convergent and divergent cognitive styles in individuals. He thus ushered in the notion that people approach problem-solving differently according to each individual's inherent characteristic of cognitive style. To summarise, Hudson's (1967) *converger-diverger* construct attempts to measure the *processing* rather than the *acquisition* of information by an individual. It aims to differentiate *convergent* from *divergent* thinkers; the former being persons who think rationally and logically while the latter tend to be more flexible and to base reasoning more on heuristic evidence.

In contrast, *cognitive complexity theories* attempt to identify individuals who are *more complex* in their approach to problem-solving against those who are *simpler* (Beiri, 1961). The instruments used to measure this concept of 'cognitive style' are either Driver's Decision Style Exercise (DDSE) or the Complexity Self-Test Description Instrument (Carey, 1991), which as discussed below are somewhat ad hoc. This approach also differs from Kelly's 1955 *cognitive complexity* / *cognitive simplicity* theory, which refers to the degree to which a respondent *differentiates* perceived elements in a given situation.

Pask (1976) extends these notions in a discussion of strategies and styles of learning. In this, he classifies learning strategies as either *holist* or *serialist*. When confronted with an unfamiliar type of problem, serialists approach problem-solving step-wise, proceeding from the known to the unknown. As they proceed, they make the simplest connections possible between the items of knowledge. By contrast holists seek an overall theoretical framework in which the problem is perceived to fall. They then explore areas within the framework until they have "filled in the whole" (Atherton, 2003).

Further characteristics of Serialists and Holists are as follows:

<u>Serialists</u>

- Build up their knowledge sequentially
- Tend to lose sight of the bigger picture
- Are impatient with co-workers who "jump around"
- Are more comfortable with inherently sequential problem-solving

<u>Holists</u> / . . .

<u>Holists</u>

- Pick up “bits and pieces” within a broad framework
- May leave gaps, or repeat themselves
- May make mistakes about the connections between things
- May over-generalise
- May be more comfortable with “topic” based learning

(Atherton, 2003)

Atherton (2003) cautions against taking obvious parallels between Pask’s Serialist/Holist theory and the convergent/divergent theory of Hudson. They do not, he claims, measure exactly the same attributes of human beings, although it would be difficult to see how a serialist could be anything other than a convergent thinker.

Ornstein’s (1973) *hemispherical lateralisation concept*, commonly called *left-brain / right-brain theory*, posits that the left hemisphere of the brain controls logical and analytical operations while the right hemisphere controls holistic, intuitive and pictorial activities. Cognitive style is thus claimed to be a single dimension on a scale from *extreme left-brain* to *extreme right-brain* types, depending on which associated behaviour dominates in the individual, and by how much. People therefore lie on a continuum between extremely *analytical* problem-solvers to extremely *heuristic*. Sonnier (1991), in a discussion of the hemispherical lateralisation concept, suggests its importance to learning among students. Left-brain students he found to be more analytical in thought processing, while right-brain students tend to be visual processors. One could conjecture that the same would apply to users learning a new system, thus making it relevant to systems development theory. Measurements are made by directly monitoring the electrical activity of the subject’s brain via electrodes placed on the scalp.

Taggart’s (1988) ‘Whole-brain human information processing theory’ classifies the brain as having six divisions, three per hemisphere, which in a sense is a refined model of the hemispherical lateralisation theory discussed above. Carey (1991) suggests that the Human Information Processing instrument derived for measuring Taggart's construct should also be used in conjunction with brain-wave monitoring. Another model of cognitive style which is both bipolar and Jungian in its origins, is the Allinson-Hayes (1996) Cognitive Style Index (CSI). This instrument also has features of Ornstein's (1973) left-brain / right-brain theory. As noted by Sadler-Smith (1999), Allinson and Hayes (1996) speculated on hemispherical differences in the brain as a possible basis for cognitive style differences and use the term "intuition" to describe "right brain" thinking (immediate judgment based on feeling and the adoption of a global perspective) and "analysis" for "left brain" thinking (judgment based on mental reasoning and a focus on detail). "Style" in this context is the dominance of one mode of thinking over the other and describes "different" rather than "better" approaches to learning, problem solving, and so on (Sadler-Smith, 1999). The same author notes similarities with other instruments. For example, the Allinson and Hayes' intuition-analysis dimension of style he thought was broadly equivalent to the wholist-analytical dimension (of Riding, 1991) and the adaptor-innovator dimension (of Kirton, 1994). The CSI was developed from an initial 129 items based on their survey of the cognitive style literature (Hayes and Allinson, 1994). These were reduced to 38 items, each rated using a 3-point scale (true; uncertain; false). 17 of these are "intuitive" items that are negatively scored (true=0; uncertain=-1; false=-2). The other 21 items are "analytic" items and positively scored (true=2; uncertain=1; false=0). Two sample items are,

"I prefer chaotic action to orderly inaction",

for intuitive, and

"I always pay attention to detail before reaching a conclusion"

for analytic. The scores have a theoretical range from 0 to 76, a high score suggesting a preference of an analytical over an intuitive cognitive style, and a low score, of course, the reverse. Allinson and Hayes (1996) reported that on average the scores typically range between 38.98 and 46.67, and that the standard deviation varies slightly from 14.21 to 16.13.

2.2.3.1 Critique of the above attempts to construct continuous, bipolar measures of 'cognitive style'

These theorists produced a number of continuous bi-polar measures which are simpler than the multi-descriptor MBTI and more focused on the precise definition of cognitive style each was trying to measure (Isaksen, Lauer and Wilson, 2003, and see Section 2.2.4.1). Additionally, they have the advantage that they can be used directly for the measurement of correlations and associations. However, most require some cognitive ability on the part of the subject, and so tend to measure some mix of cognitive level and style, rather than providing a measure of cognitive style only (Kirton, 1999). For example, in an empirical comparison of the EFT and his KAI instrument, Kirton (1978) found an insignificant correlation between the two (r = -0.3). This suggests that the KAI and EFT do not, in fact, measure the same construct, although they may have common components. It can be argued that figure recognition is related to perception and the ability to perceive figures rather than cognitive style. In other words, the EFT and its derivative, the GEFT, like the MBTI actually measures a mix of style and level. The results of Taggart, et al. together with those of Kirton cast doubt on the validity of the EFT and GEFT in research involving cognitive styles, and so as these appeared to be somewhat dated in their usage by scholars, this study looked for other alternatives.

Carey (1991) rejects measures based on Hudson's (1967) converger-diverger construct as ad hoc and as having yielded instruments for which little validation has been attempted. Scholarly IS literature surveyed from the period 1988 to 2005 inclusive contained negligible references to Hudson's construct. Consequently this study did not pursue his approach further, finding no precedent for its use in the scholarly IS research literature of the present day.

Only two articles were found since 1967 relating to the Cognitive Complexity theory of Beiri (1961) and Schroder, et al (1967); one in 1988 and the other in 1990. It was thus assumed that recent research has largely abandoned this approach for the measuring of cognitive style. Carey (1991) notes in confirmation that the existing instruments for measuring this concept; namely the DDSE and Complexity Self-Test Description Instrument (see Section 2.2.2) are ad hoc and open to question. The former, she describes as a problem-solving exercise, which asks respondents to elaborate on processes they undergo as they work the test. The latter she describes as a paragraph completion test, which is also perceptual in nature. She thus points out that these instruments measure *perceived* style rather than *actual* style. In any case, as soon as perception is involved, one is considering the capacity of mental processing of input stimuli, which differs from person to person. In other words, capacity forms part of these measures as well as style. Kirton (2004) distinguishes between capacity and style as fundamentally different dimensions of personality. In the light this argument, as well as that by Carey and the sparse use made of it since 1990, the current study did not consider cognitive complexity theory further.

The hemispherical lateralisation concept proposed by Ornstein (1973) had not shown any great predictive ability in human research by the mid-1980's, according to a literature survey by Le Gare (1983). One probable reason noted by Carey (1991) for this is the time, costs (and doubtless logistics) associated with measuring the brain activity of target respondents. She further concludes that these measurements have provided little predictive ability and hence are of no real use to IS research. As argued by Carey, Taggart's (1988) whole brain information processing theory should also be used in conjunction with brain-wave monitoring and so has the same inherent limitations. As this approach yielded little further comment in scholarly IS literature during the period 1988-2005, it was not considered further by the present study.

Carey's (1991) review of Witkin's EFT, Hudson's study, Schroder, the Jungian MBTI, Ornstein and Taggart, is not encouraging. She does, however, suggest that cognitive style theory should not be abandoned as part of IS research. After these prognoses, the present study did not consider either approach further. Carey's study did not discuss the mix of cognitive style and level, which all these theories obviously exhibit. For a summary, see Table 3.

Table 3: 'Cognitive Style' Constructs: Key Studies

Study	Cognitive Style Construct(s)	Instrument
Kelly, 1955	cognitive complexity/simplicity	**RepGrid** (Repertory Grid)
Jung, 1960	Jungian typology	**MBTI** (Myers-Briggs Type Indicator)
Witkin et al., 1967, 1971	Field dependence-independence	**EFT** (Embedded Figures Test) **GEFT** (Group EFT)
Hudson, 1966	Converger-diverger	None
Schroder, 1967, and Pask, 1976.	Cognitive complexity	**DDSE** (Driver's Decision Style Exercise)
Ornstein, 1973	Hemispherical lateralisation	Brain scan
Taggart, 1988	Whole brain human information processing	**HIP** (Human Information Processing Intrument)
Kirton, 1976	Adaptor-innovator continuum	**KAI** (Kirton Adaption-Innovation Inventory)

When it comes to the CSI, Cassidy (2004) lists the CSI among several other approaches to measuring the concept of cognitive style, but does not indicate that it has any advantages or disadvantages compared with other instruments. Hodgkinson and Sadler-Smith (2003), agree that the initial research underpinning its development, and subsequent studies, have demonstrated that it exhibits good reliability and in respect of internal consistency as measured by Cronbach's alpha. They also confirm its test-retest reliability and that a number of significant relationships have been shown with similar measures. However, they question its construct validity on the grounds of theoretical and methodological limitations associated with its development. Most specifically, Allinson and Hayes (1996) claimed that their instrument had a unifactoral structure, which Hodgkinson et al. cast doubt upon. The latter authors re-examined the Allinson and Hayes (1996) study in the light of these misgivings and found the research design to be faulty. Additionally, Hill et al. (2000) in an empirical study of 200 managers spread over four countries found significant differences between national groups in cognitive approaches and some aspects of socialisation. This suggests that the constructs measured by the CSI differ from one culture to another. In other words, the CSI might be culture-dependent. This is a serious issue in its use to measure analyst/user interactions, because in most countries today, IS staff and users come from differing ethnic backgrounds. The situation is exacerbated by the (1996) assertion by Allinson and Hayes that their instrument shows differences of cognitive style between the genders. What could also account for this, however, is that the instrument is contaminated by gender dependent constructs not related to cognitive style. Owing to these misgivings, the present study did not consider the CSI further as a measure of cognitive style, but sought one that is more independent of culture, ethnicity and/or gender.

2.2.4 The emergence of a measure of cognitive style *independent* of cognitive level

This approach to the measure of cognitive style grew out of previous efforts to develop continuous, bipolar scales. Kirton (1976) retained the basic concepts of a continuous, bipolar scale and two extremes of personality. However, his instrument, the Kirton Adaption-innovation Inventory (KAI), requires the respondent, without any imposed time constraint, to rate themselves against thirty-three personality traits, expressed in clear and simple language (see Appendix 1.1 for its format and sample item). It is thus difficult to see how cognitive level could play a significant role as no more ability than basic literacy is required.

Kirton (1999) posits that *cognitive style* and *problem-solving potential* (the latter usually measured as IQ*)* are the sole components of the more general construct of *cognitive effect*. Cognitive effect gives rise to *problem-solving processes,* which are strategies by which individuals solve problems. In short, individuals generate solutions to problems by combining their abilities with their *preferred approach* to problem-solving. *Cognitive style* can therefore be defined as *an individual's preferred approach to problem solving*. It is deduced from this that a person does not necessarily always follow one approach, but will merely *prefer* one approach to other approaches. According to Kirton (1999), this preference is highly stable for persons who are 18 years or over. This has been demonstrated empirically by several studies making use of the

KAI, results for some of which are given in Table 5(b). These show that the KAI's test-retest reliability coefficients all exceed 0.8 over periods ranging from 14 weeks to 43 months. Kirton claims further that the KAI measures this individual preference as a continuum, in relation to others, describing the degree of *cognitive structure* (formal methodology) that he/she prefers (Kirton, 1999 and 2003). This is a significant departure from the approach intrinsic to the MBTI, which claims four mutually *non-ordinal* classifications of cognitive style.

Clearly much of the above should apply to human behaviour associated with IS usage and development. However, little evidence of this was found in the literature, other than two studies by Mullany (1989, 2001). According to Mullany (1989), cognitive processes and their impact upon the problem-solving world of IS are of significance. He argues that if, for example, a user's self-conceived solution is not similar to the systems analyst's, the user is likely to reject the analyst's system as unreliable; the user being unlikely to trust the problem-solving strategy employed. However, as Mullany also notes, no more recent empirical IS studies up to the present (2005) making use of cognitive process research, were found. One might conjecture that there is no guarantee that the methods used by individuals to solve the same problem are the same or even similar. It thus becomes a daunting (if not impossible) task to forecast user satisfaction employing analyst-user cognitive process analysis alone.

None of these issues affect the alternative approach to cognitive process suggested by Kirton (1976). As confirmed by Ramaprasand (1987), cognitive style is a 'macrocosmic' concept as opposed to the 'microcosmic' concept of cognitive process. The term 'cognitive process' as used by this author, is a brain-based process, such as memory, attention, perception, action, problem solving and mental imagery. Cognitive style, on the other hand, groups different types of cognitive process into categories. As problem-solving is held to be a type of cognitive process, solutions to problems can like-wise be classed as having some similarity or dissimilarity of *approach*. Kirton's (1976) A-I theory essentially suggests two extremes of cognitive problem-solving style (adaptive and innovative), into which any problem-solving process can be categorized. Those cognitive problem-solving processes associated with an adaptive cognitive style tend to be more structured than those associated with the opposite, or have a higher degree of *cognitive structure*. Structure in this sense means greater order, precedent, structured methodology or 'correct way of doing things' (Kirton, 1999). Kirton (1999) suggests that some human beings, called *adaptors* tend to prefer the adaptive approach to problem-solving, while others (*innovators*), of course, prefer the reverse. Adaptors normally espouse cognitive structure, while innovators tend to eschew it. Adaptors use what is given to solve problems by time-honored techniques. Alternatively, innovators look beyond what is given to solve problems with the aid of innovative technologies (see Table 4). Kirton (1976) suggests that innovators tend to keep organizations on the competitive edge by encouraging investment in innovative technology. An organization which has more innovators than adaptors will, he suggests, lack the hard work based on traditional methodologies, which is necessary for it to run effectively. It is also a posit of Kirton's (1999) that the type of problem-solving style is personality-related and remains fixed for life once an individual reaches maturity (at about 18 years).

Banker and Kauffman (2004), in a 50-year review of IS research, note Ramaprasand's (1987) study, and back his position, that cognitive process research is likely to form a better basis for MIS and DDS design than cognitive style. However, Banker et al. did not cite any later IS studies which significantly employed or examined the cognitive process concept. From their review, it is evident that cognitive process and cognitive style remain current issues in IS, but that little successful, recent use of either has been reported in the literature they surveyed.

Table 4: Comparison Of Adaptor And Innovator Traits

Adaptors:	**Innovators:**
“do well” within a given paradigm;	“do differently”, seeking new paradigms and methods;
are prepared to wed themselves to systems, solving problems “in the right way”;	seek new, often unexpected, and frequently less acceptable methods;
tend to follow traditional methods of problem-solving;	have little regard for traditions, eliciting comments such as, “He wants to do it his own way, not the ‘right’ way”;
are often seen as “stuck in a groove”.	are often seen as creating dissonance.

Kirton (1999) notes that his KAI instrument exhibits a mean score of 96, a standard deviation of about 16 and has a possible range of 32 to 160 inclusive. Respondents scoring higher than the mean are classified as innovators and those lower, as adaptors. In effect Kirton (1999) also defines a third class of problem solvers, whom he refers to as *cognitive mid-scorers.* These individuals are neither strongly innovative nor strongly adaptive, and will generally obtain KAI scores from 80 to 112. They lack the technical problem-solving preferences of strong innovators or adaptors, but tend to be better facilitators by forming a *communicative link* between the extreme cognitive styles. In short, they prefer *human* to *technical* problem-solving. The KAI presents respondents with 33 character traits, on which they effectively score themselves on an invisible five-point scale. The first of these, ‘A person who is patient’ is a blind so the respondent’s rating for this trait is not added to the overall score. For the format of the KAI instrument, refer to Appendix 1.1. Kirton (2003) claims that the KAI score for an adult (over 18 years old) with work experience is

> “ very stable” and
>
> “ highly impervious to change”,

varying little with age.

2.2.4.1 Critique of Adaption-Innovation (A-I) cognitive style theory and the KAI

No scholarly criticisms were found in recent literature either of adaption-innovation theory or of the KAI. However, one might query the rather lengthy statement at the beginning of the KAI. This is,

> "How easy or difficult do you find it to present yourself, consistently, over a long period as:"

and then,

> "a person who"

prefixing each of its 33 items (see Appendix 1.1 for format). In the light of A-I theory, however, this statement may be correct. The measure is seeking the subject's *preferred style* of problem solving, and as such, there should be no suggestion that the person *cannot* follow another style. There is, nonetheless, the possibility that subjects will ignore the initial instruction and respond rather to something like:

> "To what extent are you a person who . . ."

It can be argued that this is trivial, considering the empirical evidence that the KAI is reliable (see Tables 5(a) and 5(b)). However, the degree to which the opening statement creates errors of measurement remains unknown. On the one hand, the statement as is, is academically correct. It is not obvious that the conjectured alternative,

> "To what extent are you a person who . . ."

is correct. Still, the practicality of the instrument remains a motivation. If the instrument can be used to predict aspects of system development, then it will remain of use, despite this academic difficulty.

Table 5(a): Internal reliabilities for the KAI (Kirton, 1999)

Study (cited by Kirton, 1999)	Sample Description	Sample Size	Cronbach α
Kirton (1976)	General population, UK	562	.88
Prato Previde (1984)	General population, Italy	835	.87
Goldsmith (1985)	General population, USA	214	.86
Kubes (1992)	General population, Slovak/Czek	353	.84
Tullet & Kirton (1995)	General population, France	265	.89
Tullet & Kirton (1995)	General population, Netherlands	449	.87

Table 5(b): Test-retest reliabilities for the KAI (Kirton, 1999)

Study (cited by Kirton, 1999)	Sample Description	Sample Size	Time Interval	Test-retest Coefficient
Martin (1978)	New Zealand Students	64	7 months	.82
Gryskiewicz et al (1986)	USA Managers	106	5-7 months	.84
Prato Previde (1993)	Italian Managers	55	5 months	.86
Clapp (1993)	UK work group	69	43 months	.82
				(1) Mean (2)
Pottas (Unpub.)	South African Students	121	4 months	91.2 91.1
Murdock et al (1993)	USA Students	105	14 weeks	97.4 98.3

A further reserve in respect of the KAI is Kirton's use of colloquialisms, such as 'steady plodder' or English words such as 'proliferates', which may be difficult for a non-English speaker. This, however, Kirton (1987) refutes. From time to time he notes that he has received requests from researchers to replace original words with easier ones when administering the KAI to foreign subjects. In these cases, however, he reports that statistically poorer results were normally obtained. In other words, the KAI's reliability and construct validity are not significantly reduced so long as the respondent is at least functional in English.

A further issue is the present appearance and structure of the KAI form (see Appendix 1.1). Its current format has not changed significantly over the last 25 years. It looks typically like a computer-printed form of the 1970s and 80s, all in monochrome and complete with tracks. In addition, each item is rated along a scale of dots. It is not clear from the instructions whether the respondent should always hit a dot with the X required to rate the item. Also, experience with this form showed that without verbal direction some respondents are inclined to make their crosses above or below the row of dots. This can make their rating difficult as they then miss the matrix on the underlying sensitized sheet. Furthermore, the four ratings of "very easy", "easy" "hard" and "very hard" are only displayed once above all the rating scales (see Appendix 1.1). It is thus easy for a respondent to drift off-centre, as Kirton (1999) notes. One might argue that these points are trivial. However, the appearance of the instrument could be considered second-rate by some present-day respondents and this might jeopardize the seriousness with which they complete the form. The research design, suspecting that this could be a source of error, ensured that each respondent completed the KAI with the interviewer's individual supervision so that the respondent could ask for guidance (see Chapter 4, Section 4.3.9 for details). Any belief that the KAI was a second-rate instrument was countered by a brief, verbal description of the background to the instrument, its eminence and its current popularity among researchers.

On the positive side, Buffinton, Jablokow and Martin (2002) note that Kirton's Adaption-Innovation theory

> "is well established and has been validated in practice for over 25 years, with hundreds of international journal articles and graduate theses devoted to its study and application."

The contents of Table 2 tend to confirm this. Mullany's (1989) study (see Section 2.2.4) demonstrated some contradiction of Huber (1983); that cognitive style theory can be applied fruitfully to IS and that the KAI is a successful instrument in so doing.

2.2.4.2 Empirical evaluation of the KAI

Kirton himself has collected a bibliography of well over 250 scholarly studies demonstrating the use of adaption-innovation theory and the KAI. To ensure a balanced opinion, however, the present study sought examples of this from literature *independent* of Kirton and his organization, the KAI Centre. One such opinion was by Desmedt and Valcke (2004), who found Kirton's A-I theory and the KAI to be the third most prolific with 249 citations, after Witkin (807) and Kagan (254). This means that the KAI is still not the most used instrument to measure cognitive style. Desmedt et al. (2004) note that Kagan's instrument was designed for school children, not adult system users, hence the present study did not consider it to be of further relevance. The reason for the high usage of Witkin's EFT over that of KAI, is in part historical. The KAI has only been available from the mid 70s (Kirton, 1976), while the EFT has been in use for about a decade more (Witkin, 1967). Additionally, the EFT has been used for studying cognitive styles of school children as they progress to adulthood (Witkin, 1967). The KAI on the other hand was designed from the start for adults with work experience only (Kirton, 2003).

Bobic et al. (1999), publishing independently of Kirton and the KAI centre, carried out reliability and validity tests of the KAI using three samples of historic data. These were: 203 mid-level managers, 122 international managers and 262 students. The first group completed the KAI once, and then again three months later. Only after the second occasion was this group debriefed; that is, had the KAI score and its meaning explained to them. The first group thus yielded an opportunity for a measure of test-retest validity. From the KAI scores of all three groups, Bobic et al. conducted factor analyses, from which they concluded that the KAI has high construct, content, criterion and test-retest validities.

Please refer to Table 5(a) for a selection of KAI internal reliabilities for given samples and to Table 5(b) for another selection of KAI test-retest reliabilities. As will be seen from these, the KAI is an instrument with acceptable reliability since the attendant coefficients are generally above 0.8.

When it comes to the question of whether or not the KAI contains level as a contaminant of style, the results of eleven studies are given in Table 6 (Kirton, 1999). In each case, respondents were asked to complete the KAI and the named intelligence/aptitude test. None of the correlations is significant. This infers that level, as may be measured by any one of these popular intelligence or aptitude-type tests, does not contaminate the construct of cognitive style as measured by the KAI.

Table 6: Correlations between selected intelligence tests and the KAI (Kirton, 2004)

INTELLIGENCE / APTITUDE TEST	CORRELATION WITH KAI
PRH2 General	.12
GT90B Verbal	.12
EA2A Arithmetic	.09
VMD Diagrams	.04
GT70B Non-verbal	.01
OTIS Higher	.00
CT82 Shapes	-.01
Four separate studies using Shipley	-.01
	-.04
	-.11
	-.14

Table 7 gives an analysis of citations of the KAI found in recent scholarly literature. As is evident, the KAI is still much in use as a measure of cognitive style.

Table 7:
Citation Analysis for the KAI, 2000-2005

Year	Times cited:
2000	7
2001	10
2002	10
2003	12
2004	9
2005	1
Total:	**39**

In consequence of the viability of its use in IS research (Buffinton, et al., 2002), its freedom from a cognitive level component (see Table 6) and its currency (see Table 7), the present study found the KAI to be a credible contender when performing empirical studies involving cognitive style.

2.3 The meaning, significance and measure of user satisfaction

The meaning of user satisfaction has its genesis in the meaning of satisfaction itself. Satisfaction as it occurs in occupational situations match definitions of the word in several dictionaries. For example, **Brainy Dictionary (2005)** gives one meaning as,

> "repose of mind resulting from compliance with its desires or demands."

WordNet 2.0 (2003), of Princeton University, USA, defines it, inter alia, as the

> "state of being gratified"

and then gives the example,

> "dull repetitious work gives no gratification."

Finally, the **American Heritage Dictionary of the English Language (2000)** gives one meaning as,

> "the fulfilment or gratification of a desire, need, or appetite."

Satisfaction therefore implies the satiation (gratification) of needs, as postulated by Maslow (1943, 1964. See also Appendix 2.7). Satisfaction is distinct from *motivation*. For example, when hungry one is *motivated* to eat a good meal. After this, one may well be *satisfied* with the meal, but *completely unmotivated* to eat a second meal. Satisfaction in this sense, implies at least some experience of something *responsible* for one's satisfaction. A worker given a tool with which (s)he is unfamiliar, is not able to assess their satisfaction with it until they have built up some *experience* of using that tool. Similarly, a user cannot assess their satisfaction with a system with which they have had no experience.

> ***User satisfaction*** **thus implies a summary of those factors in a user's experience of the system which satiate his/her job needs** ***after*** **some experience of using it.**

This definition of satisfaction is comparable with the expectation disconfirmation model of customer satisfaction proposed by Oliver (1980). According to this, a customer's satisfaction with a purchased item depends on matching a pre-purchase expectation with satisfactory post-purchase experience (see also Chapter 3, Section 3.3.1.2). However, no studies were found in the IS literature which directly essay any such fundamental definition of *user* satisfaction (see Sections 2.3.1 and 2.3.1.1). It is assumed rather, to have a ‘face validity’, as suggested by DeLone and McLean (1992). It is not evident that the construct of user satisfaction has followed an evolutionary process such as cognitive style. Rather, various authors have invented instruments with little reference to psychological or management theory. As demonstrated below most instruments in recent or current use employ factors, which can change as technology or other contextual circumstances change.

The next fundamental issue investigated was of the *significance* of user satisfaction to the IS field, and how it is currently measured. As discussed below, the significance of user satisfaction was found to lie in its relationship to *system success*. All the studies listed in Table 8 suggest a link between user satisfaction and system success. For example, DeLone and McLean (1992) claim that user satisfaction is

> “probably the most widely used single measures of IS success”.

They submit three reasons for this. First, that the term *satisfaction* has

> “a high degree of face validity. It is hard to deny the success of a system which its users say that they like”.

Second, the Bailey and Pearson instrument and its derivatives have

> “provided a reliable tool for measuring satisfaction and for making comparisons among studies.”

Third, that other measures of user satisfaction and system success are highly unsatisfactory, being

> “either conceptually weak or empirically difficult to obtain”
>
> (DeLone and McLean, 1992).

Table 8: Selection of studies claiming a link between user satisfaction and system success

Author(s)	Date	Research periodical	Type of study	Construct(s)
Galletta & Lederer	1989	*Decision Sciences*	Empirical validation of UIS	User Satisfaction (UIS)
Delone, Mclean	1992	*Information Systems Research*	Literature survey	Model with user satisfaction as one of six constructs contributing to system success (for more detail, see Section 2.3.3).
Downing	1999	*Information & Management*	Discussion	User satisfaction identified as an important dimension of system success
Hardgrave, Wilson, Eastman	1999	*Journal of Management Information Systems*	Literature survey and discussion	User satisfaction as a measure of system success
Hwang, Thorn	1999	*Information & Management*	Empirical study and discussion	User satisfaction used as a dimension of system success
Martinsons, Chong	1999	*Human Relations*	Empirical study using sample of 60 Asian organisations	User satisfaction used as an indicator of system success
Shayo, Guthrie, Igbara	1999	*Journal of End User Computing*	Literature survey	End-user satisfaction, End-user computing success
Lin, Shao	2000	*Information & Management*	Empirical study of 32 organisations	User satisfaction and user participation used to measure system success
Delone, Mclean	2002	*Proceedings of the 35th Hawaii International Conference on System Sciences*	Literature survey	Model with user satisfaction as one of six constructs contributing to system success: modified version of above (for more detail, see Section 2.3.3).
Delone, Mclean	2003	*Journal of Management Information Systems,*	Literature survey	Model with user satisfaction as one of six constructs contributing to system success (for more detail, see Section 2.3.3).

However, authors such as DeLone and McLean (1992, 2002), while agreeing that there is a link between user satisfaction and system success, intimate by way of their models (see Figures 1 and 2) that user satisfaction is not synonymous with system success but rather, one component of it. The current study was concerned primarily with the link between user satisfaction and how this is impacted by the cognitive styles of users and systems analysts. It thus essays to contribute in the area of system success only insofar as user satisfaction contributes. It makes no claim that user satisfaction is *synonymous with* system success. For a list of studies attempting to measure user satisfaction or related constructs found by this study, see Table 9. One-item measures of user satisfaction were considered unreliable in the light of both Bailey and Pearson's (1983) study and the prior research carried out by Wanous and

Lawler (1972), so they were not considered further (see Section 2.3.1 below). Most of the rest are factor-based. They require the user to rate his/her perceptions of a system against a number of factors. These ratings are combined to give a composite satisfaction measure (see Section 2.3.1). As noted by DeLone and McLean (1992), there is no consensus amongst these instruments as to a *best* measure of user satisfaction, so only those which have endured into recent research literature were considered further.

Table 9: Selection of empirical studies measuring user satisfaction constructs from 1981 to the present
(Table occupies pages 76 to 78)

Year	Study	Literature Source	Sample	Measure claimed	
1981	Alavi & Henderson	*MIS Quarterly*	45 Graduate students, 1 university	Overall satisfaction with a DSS	
1981	Ginsberg	*Management Science*	29 portfolio managers, 1 accounting system	Overall satisfaction	
1981	Ginsberg	*MIS Quarterly*	35 IS users	Overall satisfaction	
1981	Lucas	*Management Science*	100 executives, 1 organisation	Enjoyment, Satisfaction	
1981	Olson & Ives	*Information &Management*	83 users, 23 organisations	Information dissatisfaction difference between information needed & information received	
1982	Olson & Ives	*MIS Quarterly*	83 users, 23 organisations	Information dissatisfaction difference between information needed & information received	
1983	Bailey & Pearson	*Management Science*	32 managers, 8 organisations	User satisfaction, 39-factors	*
1983	Ives, Olson & Baroudi	*Communications of the ACM*	200 IS users	User satisfaction (Bailey/Pearson instrument)	*
1983	King & Epstein	*Decision Sciences*	76 managers, 2 organisations	User satisfaction (1 item, rated 0-100)	
1983	McKeen	*MIS Quarterly*	Application system users from 5 organisations	Satisfaction with a development project, Powers & Dickson instrument	
1984	Bruwer	*Information &Management*	114 managers, 1 organisation	User satisfaction	
1984	Edmundson & Jeffery	*Information & Management*	Users of an accounting package, 12 organisations	User satisfaction (one item only)	
1984	Jenkins, Naumann & Wetherbe	*Information & Management*	72 systems analysts, 3 organisations	User satisfaction	
1984	Langle, Leitheiser & Naumann	*Information & Management*	Systems analysts, 78 organisations	User satisfaction (1 item)	
1984	Rivard & Huff	*MIS Quarterly*	User-developed applications, 10 organisations	User complaints in respect of Information Centre services	
1984	Sanders, Courtney & Loy	*Information &Management*	373 users from 124 organisations	Overall satisfaction & Decision-making satisfaction	
1985	Barki & Huff	*Information &Management*	42 executives, 9 organisations	User information satisfaction (based on the Bailey/Pearson Instrument)	*
1985	Doll & Ahmed	*Information & Management*	154 IS managers from 55 organisations	User satisfaction	
1985	Mahmood & Medewitz	*Information & Management*	48 graduate students, 1 DSS	User satisfaction	
				*Used Bailey-Pearson Instrument or a derivative	

Table 9: Selection of empirical studies measuring user satisfaction constructs from 1981 to the present

Continued from page 76

(Table occupies pages 76-78)

Year	Study	Literature Source	Sample	Measure claimed	
1985	Raymond	*MIS Quarterly*	IS users, 464 organisations	Controller satisfaction (Modified Bailey/Pearson instrument)	*
1985	Rushinek & Rushinek	*Information &management*	4448 users of 1 system	Overall user satisfaction	
1985	Sanders & Courtney	*MIS Quarterly*	Financial DSS users from 124 organisations	Overall satisfaction & Decision-making satisfaction	
1986	De Sanctis	*MIS Quarterly*	171 HR professionals	Top management & personnel management satisfaction	
1986	Lehman, van Wetering & Vogel	*Information &Management*	DP managers, business graphics, from 200 organisations	Software & Hardware satisfaction	
1986	Mahmood & Becker	*Journal of MIS*	118 managers over 59 organisations	User satisfaction	
1986	Rushinek & Rushinek	*Communications of the ACM*	4448 users	Overall user satisfaction	
1987	Cats-Baril & Huber	*Decision Sciences*	101 students, 1 tertiary institution	Satisfaction with a DSS	
1987	Hogue	*Journal of MIS*	DSS users, 18 organisations	User satisfaction (1 item only)	
1987	Mahmood	*MIS Quarterly*	61 IS managers, 1 system	Overall satisfaction	
1987	Nelson & Cheney	*MIS Quarterly*	100 top-/mid managers	User satisfaction (Bailey/Pearson instrument)	*
1987	Raymond	*Information &Management*	IS users from 464 organisations	User satisfaction (Modified Bailey/Pearson instrument)	*
1987	Taylor & Wang	*Proceeding of the Eighth International Conference on Information Systems*	93 students, 1 college	User satisfaction with an interface	
1988	Baroudi, Orlikowski	*Journal of Management Information Systems*	358 employees, 26 organisations	User information satisfaction (UIS)	*
1988	Doll & Torkzadeh (1988)	*MIS Quarterly*	96 end-users, 5 organisations	End-user satisfaction	
1989	Davis	*MIS Quarterly*	152 users	Acceptability	
1989	Galletta & Lederer	*Decision Sciences*	92 managers	User information satisfaction (UIS)	*
1989	Mullany	Master’s Thesis, Department of Accounting, University of Cape Town	34 users, 10 organisations	User resistance as complaints made in private	
				*Used Bailey-Pearson Instrument or a derivative	

Table 9: Selection of empirical studies measuring user satisfaction constructs from 1981 to the present

Continued from page 77

(Table occupies pages 76-78)

Year	Study	Literature Source	Sample	Measure claimed	
1996	Collopy	*Management Science*	401 users, 1 organisation	User satisfaction (1 item only)	
1997	Ryker, Nath, Henson	*Information Processing & Management*	252 users	User satisfaction, User expectations	
2000	Jiang, Klein, Crampton	*Decision Sciences*	200 users	User satisfaction by UIS and using the 22-factor SERVQUAL instrument	*
2001	McGill, Lee, Loh, Seow & Wong	*4th Western Australian Workshop on Information Systems Research*	149 undergraduate students	Doll & Torkzadeh's (1988) instrument (only 10 of 12 items, slightly modified wording)	
2002	Aladwani	*Journal of End User Computing*	143 end-users, 24 organisations	Doll & Torkzadeh's (1988) instrument	
2002	Kim & Lee	*Information Systems Research*	14,594 (human) browsers, 4 internet business domains	Six proposed dimensions of architectural metrics for Internet businesses **vs** User satisfaction, customer loyalty	
2002	McKinney, Yoon & Zahedi	*Information Systems Research*	568 undergraduate & postgraduate university students, 1 university	Web-Information Quality satisfaction, Web-System Quality satisfaction and Overall Web-user satisfaction	
2003	Shaw, Lee-Partidge & Ang	*Journal of End User Computing*	57 end-users, 1 organisation	User information satisfaction (UIS) and End-user satisfaction (Doll and Torkzadeh	*
2005	Cheung & Lee	*Proceedings of 38th Hawaii Internat. Conf. on System Sciences*	515 university students, 1 organisation	E-portal user satisfaction	
				*Used Bailey-Pearson Instrument or a derivative	

Links between system usage, and user involvement were not demonstrated conclusively in any of the literature surveyed (Baroudi, Olson and Ives, 1986, and Barki and Hartwick, 1989). DeLone and McLean (2002) conjecture that system usage is an important contribution to system success. However, they intimate that user satisfaction is a separate input to system success, distinguishable from usage or user involvement. The present study thus does not focus on issues of system usage and user involvement, examining instead studies which specified user satisfaction alone. It does, however, discuss the DeLone/McLean (1992 and 2002) Models of IS Success into which measures of satisfaction and acceptability fit (see Section 2.3.2).

2.3.1 Factor-based measures of user satisfaction

The best documented and researched of all composite and *allegedly* complete measures of user satisfaction found in the literature are Bailey and Pearson's (1983) 39-Factor Instrument and its derivative, the User Information Satisfaction short-form, or UIS (see Appendix 2.2). Of the 45 studies listed in Table 9, 37 occurred after the advent of the Bailey/Pearson instrument and the UIS of Baroudi, et al. (1983). Of the 37 studies, 9 (24%) explicitly mention either or both. Almost all of the other 28 reference the Bailey, et al. (1983) and Baroudi, et al. (1983) articles, which discuss these instruments. Among those articles by other authors, which refer to them, is the study by Ryker, Nath and Henson (1997). This notes that the UIS modification of the Bailey and Pearson (1983) instrument was

> "the best available general purpose measure of user satisfaction",

and that it has become

> "widely utilized".

They used the UIS instrument in their (1997) empirical study of the relationship between user satisfaction and user expectations. Galletta and Lederer (1989) demonstrated the UIS's test-re-test reliability in an empirical survey targeting 92 managers and top executives. They did, however, question its construct validity. Kim and Lee (2002), in an empirical study to validate their six proposed metrics for the architectural quality of internet businesses, agree with this analysis.

In a description of their instrument, Bailey and Pearson (1983) argue that a 'standard measure' of user satisfaction should encompass a *complete* list of relevant factors. This is supported by Wanous and Lawler (1972), who concluded, in an empirical study of worker job satisfaction, that single-item (one-scale) psychometric measures are generally less reliable in the psychometric sense than are composite measures. Bailey and Pearson's 39-factor questionnaire was developed after the identification and testing of many more factors affecting user satisfaction (Bailey and Pearson, 1983). 32 managers in 8 organisations were interviewed and after each interview the respondent was asked to evaluate their overall sense of satisfaction with their current computer experiences. This was compared with measures of user *perceptions* of specific aspects of the system. Using these results, Bailey and Pearson developed their measure of computer user satisfaction. This is the sum of a user's positive or negative reactions to 39 factors, as rated on four seven-point scales per item, each weighted by the respondent's perception of that factor's *importance*. Importance was measured using a fifth seven-point scale per item. Bailey and Pearson (1983) found that their sample of users rated as most important of the 39 factors, *accuracy*, *reliability*, *timeliness*, *relevancy* and *confidence in the system*. The factors of *least* importance were found to be *feelings of control*, *volume of output*, *vendor support*, *degree of training*, and *organisational position of EDP (the IS department)*.

Ives, Olson and Baroudi (1983) empirically tested Bailey and Pearson's instrument together with three older measures of user satisfaction. These were Gallagher's questionnaire, Jenkins and Rickett's 20-item measure, and Larcker and Leasing's perceived usefulness instrument. They found Bailey and Pearson's instrument to be the most predictive of the four and to have the greatest construct validity. However, the Bailey/Pearson instrument requires 5 x 39, or 195 individual seven-point scale responses. Errors of attrition, caused by the increasing carelessness of the respondent as they fill in a long questionnaire, were seen as a possibility. This motivated Ives et al. to construct their shortened version of the instrument (see above). In addition, the Pearson instrument is dated, so that issues presented in this instrument which applied in 1983 have changed with the advent of new technology. For instance, Internet-based systems are now common, but did not exist in 1983, as noted by Doll and Torkzadeh (1988).

Ives, Olson and Baroudi's (1983) User Information Satisfaction (UIS) Short Form (see Appendix 2.2) was found to be in significant use at the present time. As is evident from Appendix 2.2, the latter requires the user to rate his/her satisfaction with a given system in respect of 13 factors. Two seven-point scales are provided per factor, making 26 individual responses in all necessary (see Appendix 2.2 for the actual instrument). After replicating Bailey and Pearson's (1983) study by means of a postal survey, they showed that the construction of a shortened version would be possible with little loss of validity. First, they found a very high correlation between the weighted and non-weighted factors of Pearson's instrument, suggesting that the importance rating was not necessary. Their shortened version omitted the weightings, the least significant two thirds of the factors (as determined by factor analysis) and two of the four seven-point scales per item. This resulted in the UIS Short Form (see Appendix 2.2). Ives et al. performed a factor analysis on this instrument, thereby decomposing its definition of user satisfaction into three components. These were *IS staff and service*, *quality of output*, and *user knowledge and involvement (including quality of training)*.

Raymond (1987) investigated the use of the UIS Short Form in the specific context of small organisations (of 20 to 250 employees). He modified the Short Form slightly by re-introducing the factor, *vendor support of hardware and software*; one of the 26 factors which Ives, et al. had discarded. This, he argues, is a critical success factor in the case of small businesses since their user-managers are in direct contact with vendors and service bureaux. Using postal responses obtained from 464 computerised firms, Raymond found the inter-item reliability scores (measured as Cronbach alphas) to range from 0.81 to 0.95, with the overall user satisfaction measure having a reliability co-efficient of 0.91. He thus concluded that his version of the UIS Short Form is reliable. As this differed by only one factor from the original Short Form, the reliability of the UIS measure was also inferred. Raymond performed no further tests for content validity, but argues in favour of accepting the results of those conducted by Ives et al (1983). With the aid of factor analysis, he found an underlying structure of factors, which, he claims, confirms the instrumental definition of the construct, user satisfaction, and demonstrates the instrument's construct validity. With or without this addition, the UIS short form has been used to measure user satisfaction up to the present. For example, Tan and Lo (1990) replicated Raymond's (1988) study and agreed with his conclusions that with the factor *vendor support of hardware and software* added, the UIS is reliable and exhibits construct validity for organisations of any size.

Lawrence and Low (1993) examined user satisfaction in the context of user-led development of systems. In this research, a small group of users were entrusted with the management of a project. They were also required to represent the users throughout the development life-cycle from the requirements determination to the eventual implementation of the system. Lawrence *et al.* surveyed the users of two systems which were implemented in a user-led development environment. They administered the UIS instrument to measure user satisfaction. They developed their own instruments to examine various factors, which could possibly influence user satisfaction. After analysing the results, they concluded that user perception of representation had the most significant influence on user satisfaction. As their study was essentially a measure of association between this measure and the corresponding UIS scores, the construct validity of the UIS was further demonstrated.

As previously mentioned, Doll and Torkzadeh (1988) noted that with changes in technology, a new type of user, the *end-user*, was emerging. They identified end-users as users who tend to interact with a software interface only, while previously users interacted with analysts and operational staff as well. This led them to critique previous measures of user satisfaction as specific to conventional users and to produce their own instrument which specifically targeted *end-users*. They generated a 40-item pilot questionnaire based on previous research and conjecture in the literature. They then administered this to 96 end-users distributed roughly equally over a manufacturer, two hospitals, a municipal office and a university. Internal reliability and factor analysis then followed which enabled them to reduce the 40 items to the 12 most consistent and with the greatest construct validity. The essentials of the resulting instrument are given in Appendix 2.5.

McKinney, Yoon and Zahedi (2002) developed a model and instruments for measuring Web-customer satisfaction during the information phase; this being the stage in which customers search for information regarding their intended purchases. Their development combined Oliver's (1980) expectation-disconfirmation model of consumer satisfaction with existing empirical theories in user satisfaction. For details of Oliver's model, see Section 2.3 and also Chapter 3, Section 3.2.2.2, where the same model is described prior to its application in the present study. McKinney, et al. separated the notion of *Web site quality* into two divisions of *information quality (IQ)* and *system quality (SQ)*, and then proposed nine key constructs for Web-customer satisfaction. The measurements for these constructs were developed and tested in a two-phase study. In the first phase, the IQ and SQ dimensions were identified, and instruments for measuring them were developed and tested.

In the second phase, using Web-IQ and Web-SQ as the basis for formulating first-order factors, they developed and empirically tested instruments for measuring IQ and SQ-satisfaction. This phase further involved the design and testing of second-order factors for measuring Web-customer expectations, disconfirmation, and perceived performance regarding IQ and SQ. The instruments concerned rated the analysis of the measurement model and indicate that the proposed metrics have a relatively high degree of validity and reliability. The study output includes instruments for measuring the key constructs in the analysis of Web-customer satisfaction within Oliver's (1980) expectation-disconfirmation paradigm. Some of the factors such as *understandability, reliability* and *usefulness* are found in other instruments discussed above. Others, such as *navigation* apply specifically to web-based systems as opposed to other systems.

As is evident from Table 9, most instruments in use to measure user satisfaction or a related construct are factor-based. Also, most of these are based on previous factor-based instruments, which can be traced back to the Bailey/Pearson instrument, the UIS or any other of the studies discussed above. For instance, Cheung and Lee (2005) in their development of an instrument to measure user satisfaction with e-portals, cite Bailey and Pearson's (1983) instrument. They base their own instrument on that of McKinney, Yoon and Zahedi (2002), which in turn is based primarily on instruments from prior studies such as those by Ives and Olson (1984), Doll and Torkzadeh (1988, 1994), and DeLone and McLean (1992).

2.3.1.1 Critique of factor-based measures of user satisfaction

None of the instruments discussed above rigorously define their construct of user satisfaction beyond a number of factors which accumulatively they believe to comprise the construct (see Section 2.3). Realising this defect, Cheney and Mann (1986) called for more empirical research on the factors which influence the success of end-user computing. Little subsequent effort which shed new light on the matter could be found in the literature, however. All factor-based instruments run the risk of including factors irrelevant to the respondent, while omitting some that may be highly significant to him/her. This is further exacerbated by the ongoing changes in the work environment, including changes in information technology. Doll, et al. (1988) indicate one of these: the emergence of end-users as opposed to more conventional users (see Section 2.3.1 above). With such changes, factors will change and instruments will need to be updated. This means that time-wise studies, if accompanied by significant changes in technology or job context, would be open to question.

Another issue with most of these instruments is their lack of theoretical underpinning, by psychological or managerial theory. For example, consider Herzberg's (1959) two-factor theory of motivation, still much used in research and taught in tertiary courses in education, psychology and management (see Appendix 2.7). All the IS literature sources on measuring user satisfaction (see Table 8) were scanned for references to Herzberg's theory, and apart from

Mullany's (1989) R-Score, Zhang and von Dran's (2000) research and Cheung and Lee's (2005) study, none were found. In other words, almost none of the existing instruments in use were developed in the light of Hertzberg's theory, despite its enduring credibility as a motivational model. The reason for finding this anomalous is that Herzberg establishes a link between his so-called "hygiene factors" and employee opinion and complaint (see Appendix 2.7). A computer-based system is a tool of the trade and very much a means to an end. It is thus part of a user's *job context* rather than *job content*, and would therefore be expected to deliver hygiene factors, or not deliver them as the case may be (see Appendix 2.7). A multi-factor user satisfaction instrument really only rates the presence or absence of hygiene factors. For example, consider one of Bailey and Pearsons (1983) factors: *system accuracy*. If a respondent rates this as less than the highest score, then the corresponding hygiene factor is either missing, or of insufficient strength to avoid some dissatisfaction. This is further supported by the definition of user satisfaction employed in this study: the user is only in a position to assess his/her satisfaction with a system after some experience with that system (see Section 2.3). In short, the respondent would be *complaining about* some *missing quality* in his/her *job context*. This analysis unmasks *all* factor-based instruments discussed above, as being recorders of *users' complaints*, and suggests that user satisfaction could be measured by recording users' complaints only. This is explored further in Chapter 3, and is developed to give the measure of user satisfaction employed in this study.

It was also important in this study to measure system success repeatedly over time, as without this, time-wise studies of user satisfaction over a period of system usage would be impossible. As argued by Baroudi, et al. (1983), the Bailey/Pearson instrument may well be unreliable on its *first* use on the grounds of attrition, let alone on repeated measurements. In defence of the factor-based instruments, however, none was developed with extended repeated use in mind. As confirmed by Sethi and King (1999) in a discussion comparing typical UIS instruments with non-linear measuring techniques of user satisfaction, the UIS type of measurements are still very much in use. For example, in an empirical study using a sample of 200 IS users, Jiang, Klein and Crampton (2000) use the UIS to verify the 22-factor SERVQUAL instrument based on the responses of their sample of users to both questionnaires; once again demonstrating the continued use of the UIS in recent times. In short, the UIS is still respected as a measure of user satisfaction, or at least it remains a yard-stick for the construct validity of other instruments purporting to do so.

There is ambiguity in the literature as to whether the UIS Short Form is intended to rate all organisational information systems used by the respondent, or only to one. For example, item 2:

> "Processing of requests for changes to existing systems",

and item 4:

> "Users' understanding of systems"

definitely imply ratings for a number of systems (see Appendix 2.2). The remaining eleven responses could apply either to *all* the systems used or just to *one* of them. It is, however, stated in Baroudi and Orlikowski's (1988) study that the UIS Short Form is a measure of the

> "success or effectiveness of an information system" (singular).

This ambiguity may detract from the reliability of the UIS.

Like the Bailey/Pearson instrument, the UIS needed to be usable for repeated measurements. At first sight it is much shorter than the former, and so might have appeared usable. However, two factors mitigated against its full use:

- If the 26 scales are regularly presented to the same user over the passage of time, the possibility of attrition errors is still a threat; and
- The respondent may repeat previous responses to corresponding scales rather than the *status quo* of the system at a given point in time.

Unlike the Bailey/Pearson instrument, however, this instrument still is used by current research studies, (see Lin and Shao, 2000) so it was retained as a means of validation.

McKinney et al.'s (2002) model seems complex and largely based on previously identified factors. Its departure was to regroup factors according to Oliver's (1980) customer satisfaction model of expectation and dissociation. Additionally they classify factors into system quality and information quality factors; something which they claim helped to identify 'key constructs' for analysing web customer satisfaction. However, it is not clear why they chose Oliver's model, as others exist, such as Tse and Wilson's (1988) *perceived performance model* of customer satisfaction.

The present study found McKinney et al.'s (2002) research to provide a number of factor-based instruments which in many ways add little more than prior instruments in terms of factors. It is true that their instruments all show high construct validity and reliability statistics, but this in many cases is nothing new. Most of the factors they identified came from instruments in which this was already known. They also did not investigate issues such as motivation or align themselves to motivational theorists such as Herzberg or Maslow when discussing issues that may motivate or demotivate web site customers making use of commercial sites. They did, however, achieve two secondary objectives:

1) to demonstrate that several of the factors identified as system user satisfiers by prior studies also apply to the somewhat different technology of web sites and customer satisfaction; and
2) to provide a reasonably sound basis for later studies which did show stronger relationships to motivational theory, such as that by Cheug and Lee (2005, see Section 2.3.3).

2.3.2 Multi-dimensional models of system success

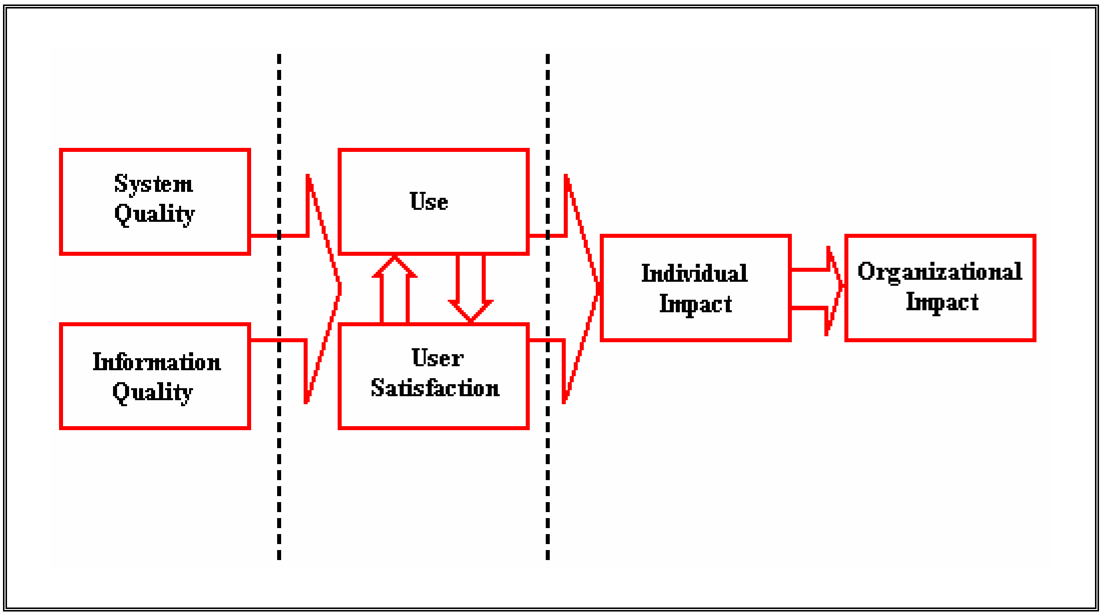
The previous instruments essayed to measure single, bipolar constructs such as *user satisfaction* and *technical acceptability*. A departure from this came with DeLone and McLean's (1992) proposal that user satisfaction is but one of six basic constructs which contribute to an overall notion (not a measure) of *system success.*

They claimed these to be:

- System Quality;
- Information Quality;
- System Use;
- User Satisfaction;
- Individual Impacts; and
- Organizational Impacts.

They then developed a model of system success (the DeLone and McLean (D & M) IS Success Model), represented graphically in Figure 1. This shows the six constructs and their postulated interrelationships. As is evident from Figure 1, system quality and information quality are input requirements to the interactive processes occurring between system usage and user satisfaction. The initial result is a certain user impact which in turn creates an accumulative organizational impact (from all the user impacts).

Figure 1: DeLone and McLean (1992) IS Success Model.



Initially, DeLone and McLean (1992) did not aim to produce a single measure of system success, but rather a research framework for how their six components of system success and the associated interactions should be studied. This recognizes user satisfaction definitively as at least a component of system success. It also suggests some elements upon which a composite measure of system success (their 'independent variable of IS success') could be based. As far as the selection of success dimensions and measures were concerned, they suggested that, where possible, 'tested and proven measures should be used' (DeLone and McLean 1992), but did not appear to favour any one in particular.

They suggest that their

> "success model clearly needs further development and validation before it could serve as a basis for the selection of appropriate IS measures . . ."
> (DeLone and McLean 1992).

The motivation for this pioneering effort was vindicated when their (1992) study invoked significant reaction from researchers. By 2002, DeLone and McLean were able to demonstrate the wide, scholarly examination of their model (see Table 10).

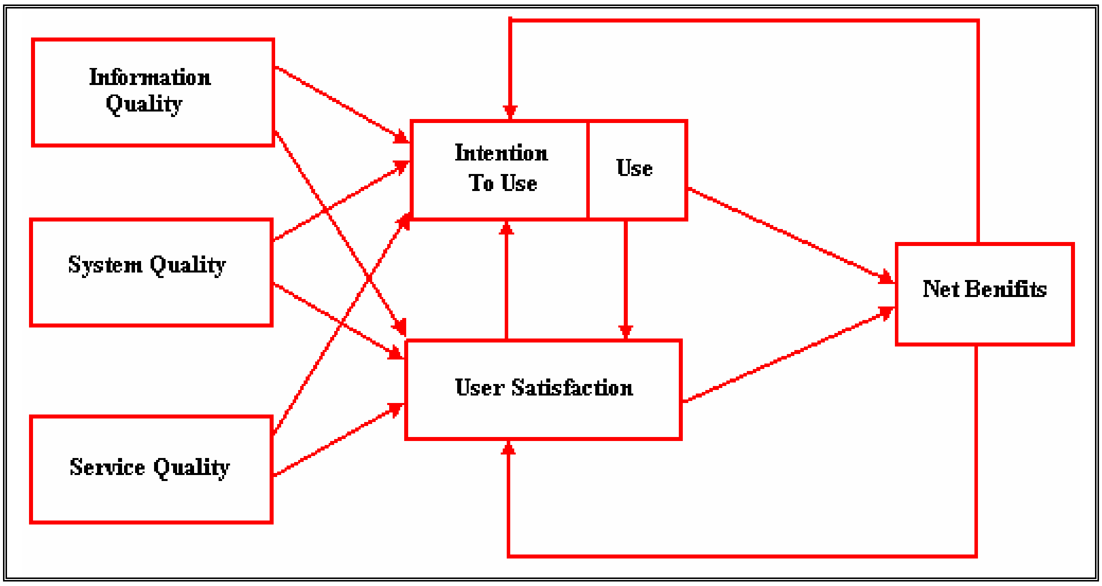
Table 10: Journal Articles Citing the DeLone and McLean IS Success Model
(Excludes a number of conference proceedings that also cite the model)

Journals	**Number of Articles Citing the Model**
Information & Management	24
Journal of Management Information Systems	11
MIS Quarterly	15
European Journal of Information Systems	10
Information Systems Research	7
Decision Sciences	6
Omega – International Journal of Management Science	6
Management Science	4
IEEE journals	4
Communications of the ACM	2
IBM Systems Journal	1
Other journals	54
Total	**144**

(DeLone and McLean, 2002)

After an examination of several articles discussing the original model, they published in 2003 an updated version of their model (see Figure 2). This added the further input factor of *Service Quality* and showed more detailed coupling between the input factors and the interactive elements of *User Satisfaction* and *Use*. *Use* was subdivided into *Use* and *The intention to use*. The *individual* and *organisational* outputs were replaced by the factor, *Net Benefits*.

Figure 2: Updated DeLone and McLean (2003) IS Success Model.



2.3.2.1 Critique of the D & M Models

Seddon (1997) suggests that there is a mix of causal (variance) and process explanations in the D & M IS Success Models. This, he argues, can lead to potentially confusing meanings. He consequently proposed a reformulation of the D & M Model into two, partial-variance models. DeLone and McLean (2002), however, criticize this as an unnecessary complication, claiming that their model is process-based with causality as the flow.

The D & M IS Success Model's wide acceptance does provide a framework, at least metaphorically, into which later measures of satisfaction can be, and were placed; for example the study by Cheung and Lee (2005). It does not, however, give guidance as to the most appropriate instrument for the measuring of user satisfaction.

2.3.3 Measurements of user satisfaction or dissatisfaction related to Herzberg's two-factor theory of motivation

Despite its continued use (see Appendix 2.7), Herzberg's theory of motivation has not escaped significant criticism. As mentioned in Appendix 2.7, for example, Caston and Braito (1985) claim that this theory tries to explain job satisfaction, rather than work motivation, and does not successfully measure job satisfaction. Locke (1983) rejected the idea that there can be two mutually exclusive sets of factors which satisfy or dissatisfy. This calls into question the link between employee satisfaction and motivators, or between employee dissatisfaction and missing hygiene factors. The present study also identified a logical difficulty with Herzberg's hygiene factors, in that they are phrased as *positive* factors, which need to be *present* in order not to dissatisfy. This problem can be illustrated by the following scenario. A certain user is satisfied with all the systems she uses, until an informal discussion with a friend, who does much the same job in a rival organisation. After the discussion, the user believes that her own systems are outdated and inferior, so dissatisfaction is exhibited from then on. In other words, dissatisfaction came into being after an *extrinsic event*. Herzberg's theory would suggest that the belief that her systems are state-of-the-art, or at least that no other suite of systems is better, is a hygiene factor, reduced by her new beliefs after the discussion. Herzberg's position in such cases is contrived, making hygiene factors difficult to identify and measure. Neither the user nor anybody else may have been aware of the hygiene factor until the corresponding dissatisfaction set in. This study found that it would be much more tractable to say that a *new dissatisfier* came into being after the discussion, the intensity of which can be measured on, say, a multiple-point scale.

Despite the criticisms of Herzberg's theory above, the present study found that his hygiene factors are indeed related to the problem-factors of factor-based instruments (see Chapter 3, Section 3.3.1.2 and Table 13). It is also noted that Herzberg's theory applied to *job satisfaction* rather than to *satisfaction with a tool of the trade* (see Chapter 3, Section 3.3.1.2). In other words, Herzberg's theory needs modification if it is to apply to computer-based systems, as they *are* tools of the trade. A treatment of a suggested modification to Herzberg's theory for computer systems, is given in Chapter 6, Sections 6.3 and 6.3.1, where a new "mechanical" model of motivators and resistance, specifically for the tasks of system usage and development, is described. This legitimises further the description of Herzberg's theory, despite the misgivings articulated above, as a *point of departure* for this development.

Zhang and von Dran (2000) devised a model of website design which parallels Herzberg's two-factor theory of motivation (see Appendix 2.7). Their study focused on two levels: specific features or core design factors, and categories. They used the term "factor" to refers to both of these. They devised an instrument for measuring 'satisfiers' and 'hygiene factors' for users of web sites. The first phase of their research identified a list of 44 core design factors after surveying 76 web site users. In the second phase, 79 different subjects were asked to categorize these core factors as either motivators (satisfiers) or hygiene factors. Both phases used samples of students (undergraduate to doctoral) together with academic staff from a private university in the United States. However, none participated in both phases. In the second phase, the respondents were initially given a lecture on Herzberg's two-factor theory, and their comprehension of this was verified by a short test. The 44 design core factors they found, they asked the second sample of respondents to classify into satisfiers and hygiene factors. (see Tables 11(a) and 11(b)). As can be further seen from these tables, the web sites were extremely variant in design, suggesting that the results are potentially generalisable to the population of web sites. These authors provide chi-square values for the significances of differences between the frequencies of respondents who classified each item as a motivator against those who classified it as a hygiene factor. A significant finding of their study was that motivators tend to become hygiene factors with the passage of time and with further experience of the web site.

Based on McKinney, Yoon and Zahedi's (2002) measure of Web-user satisfaction, Cheung and Lee (2005), in a study of users' satisfaction with e-portals, make use of a factor-based instrument with seven-point scales (see Appendix 2.6). Their study demonstrates the clear merits of this instrument, and supports the currency of some factors from previous instruments (see Table 12). It also describes satisfaction factors as *asymmetric*, meaning that the impact of positive and negative ratings of the same factor are different and should be processed differently. In fact, they postulated that a negative rating suggests a *higher* impact than a positive rating. To test this, a large number of first-year university students were surveyed on-line after they had had six weeks' e-portal experience. From these, 515 usable questionnaires were produced. They found that while the internal reliability of their instrument was high, their hypothesis tested inconclusively; that is, the study could not show strongly significant asymmetric differences between the positive and negative ratings of the factors tested (Cheug and Lee, 2005). The present study thus accepts their research as a recent verification of some of the factors used in prior instruments. Cheung and Lee's (2005) study also demonstrates that some of the user satisfaction factors which applied in the past also apply to users of systems incorporating newer technologies such as e-portals. For comparisons, see Table 12.

Table 11(a): Core web site design factors found to be Herzberg-type motivators by Zhang and von Dran (2000)

CORE DESIGN FACTORS FOUND TO BE MOTIVATORS:	% Respondents who		Difference (%)	χ 2
	Agreed	Disagreed		
High/low level of learned new knowledge and/or skills by doing the surfing activity on the Website.	80½	19½	61	.000
Presence/absence of use of humour.	79	21	58	.000
Fun/no fun to explore.	78	22	56	.000
Presence/absence of external recognition of the website (e.g. the site won awards, number of times the Website has been visited).	76	24	52	.000
High/low reputation of the Website owner.	72	28	44	.000
Appropriate/inappropriate detail level of information.	71½	28½	43	.000
Presence/absence of multimedia.	69½	30½	39	.000
Presence/absence of controversial materials.	69½	30½	39	.000
The surfing activity has a high/low level of challenge	67½	32½	35	.001
Users can/cannot control opportunities for interaction.	64½	35½	29	.008
Users can/cannot control complexity of mechanisms for accessing information.	63½	36½	27	.015
Users can/cannot control difficulty level of information to be accessed.	62½	37½	25	.022
Presence/absence of novel (new) information.	61½	38½	23	.042
Presence/absence of eye-catching images or title on the homepage.	61½	38½	23	.042
Visually attractive/unattractive screen layout.	59½	40½	19	.091
Importance/lack of importance of the surfing activity to the user.	57	43	14	.185
Presence/absence of assurance that user entered data is encrypted.	56½	43½	13	.251
Attractive/unattractive overall colour use.	51½	48½	3	.821
Users can/cannot control how fast to go through the Website.	50½	49½	1	.909

Table 11(b): Core web site design factors found to be Herzberg-type hygiene factors by Zhang and von Dran (2000)

CORE DESIGN FACTORS FOUND TO BE HYGIENE FACTORS:	Respondents who Agreed	Respondents who Disagreed	Difference	χ 2
Attractive/unattractive screen background and pattern.	50½	49½	1	.910
Complete/incomplete coverage of information.	51½	48½	3	.821
Biased/unbiased information.	54	46	8	.480
Presence/absence of identification of site owners/designers.	55	45	10	.359
Presence/absence of access requirement.	55	45	10	.365
Structure of information presentation is logical/illogical	55½	44½	11	.305
Fl 1-2 Presence/absence of gender or racial/ethnic biases and stereotypes.	55½	44½	11	.352
Authorized/unauthorized use of the user's data for unanticipated purposes.	57½	42½	15	.169
Relevant/irrelevant information.	57½	42½	15	.174
Presence/absence of indication of system loading/responding time.	59	41	18	.138
Presence/absence of improper materials.	62	38	24	.026
Authorized/unauthorized collection of user data.	63½	36½	27	.015
Up-to-date/outdated information.	64½	35½	29	.010
Users can/cannot control order or sequence of information access.	64½	35½	29	.010
Presence/absence of overview, table of contents, and/or summaries/headings	64½	35½	29	.009
Effective/ineffective navigation aids.	67	33	34	.002
Accurate/inaccurate information.	69½	30½	39	.000
Information on the Website stays/does not stay for a period of time.	70½	29½	41	.000
Sharp/fuzzy displays.	70½	29½	41	.000
Support/lack of support for different platforms and/or browsers.	71½	28½	43	.000
Stability/instability of the website availability.	73½	26½	47	.000
Adequate/inadequate brightness of the screens/pages.	73½	26½	47	.000
Presence/absence of indicators of the user's location within the Website.	76½	23½	53	.000
Clear/unclear directions for navigating the Website.	77	23	54	.000
Content that supports/does not support the Websites intended purpose.	79	21	58	.000

Table 12: A comparison between the Cheung /Lee dimensions of e-portal success with previous models for user satisfaction and system acceptability

Dimensions of Information Quality (Cheung / Lee) *Fits with the D & M Model as a suggested Information Quality Input (see Figures 1 and 2)*			**Equivalent Factors, from previous studies**	
Dimension	**Definition**	**Manifest Variables**	**Pearson and UIS short form**	**Technology Acceptance Model***
Understandability	Concerned with such issues as clearness and goodness of the information	Clear in meaning Easy to understand Easy to read		Useable
Reliability	Concerned with the degree of accuracy, dependability, and consistency of the information	Trustworthy Accurate Credible	Accurate Reliable	
Usefulness	Users' assessment of the likelihood that the information will enhance their decision	Informative Valuable	Timely	Useful
Dimensions of System Quality (Cheung / Lee)				
Fits with the D & M Model as a suggested System Quality Input (see Figure 1)			**Equivalent Factors, from previous studies**	
Dimension	**Definition**	**Manifest Variables**	**Pearson and UIS short form**	**Technology Acceptance Model***
Access	Refers to the speed of access and availability of the web site at all times	Responsive Quick loads	Short response time	
Usability	Concerned with the extent to which the web site is visually appealing, consistent, fun and easy to use	Simple layout Easy to use Well organized		Usable
Navigation	Evaluates the links to needed information	Easy to go back and forth A few clicks	Short response time	

***see Appendix 2.3**

Table compiled from: Bailey and Pearson (1983), Ives, Olson and Baroudi (1983), Baroudi and Orlikowski (1988), DeLone and McLean (1992), Cheung and Lee (2005)

By contrast with the types of instruments discussed up to now, unstructured instruments enable records of the respondent's unsolicited views. In short, the data gatherer interviews the respondent and asks him/her to elaborate on those things about the system which cause satisfaction or dissatisfaction. This can be generalised to a time-wise diary of the user's views and feelings and hence provides a way of showing how the user's perceptions change over a period of time. Such methods are common in psychological and medical research (see Smith, et. al., 2003). The limitation of this approach is its failure to produce quantified data (Mullany, 2001). In a study to examine the impact of cognitive style on user resistance, Mullany (1989, 2001) developed a method of measuring user resistance, based on Herzberg's hygiene factors, by way of semi-structuring unstructured responses. User resistance was measured at personal interviews with the key user of each system selected for investigation. The user was asked to list the problems which (s)he recalled had occurred during the system's development and implementation. (S)he was asked, in effect, to make complaints, in confidence, against the system and/or its manner of implementation. Then (s)he was requested to rate the severity of each complaint on a seven-point scale (with 7 representing the most severe weighting). The sum of severities of all the complaints measured was taken as his/her resistance score or R-Score (see Appendix 2.4). This procedure agrees with Herzberg's scenarios (see Appendix 2.7) in which complaints are noted as symptoms of inadequate or missing hygiene factors.

The main question underlying Mullany's (1989) study was,

> "Is there a relationship between user resistance to a given information system and the difference in cognitive style between the user and the analyst?"

This issue dictated the need to measure user resistance and cognitive styles in quantifiable ways. The latter was measured using Kirton's (1976) KAI as described above (see Section 2.2.3). The results of Mullany's (1989) study are succinctly summarised by Kirton (1999), who states,

> "Mullany (1989) found that the larger the "cognitive gap" between systems analyst advisors and their clients the more complaints were received."

2.3.3.1 Critique of the measures of user satisfaction/dissatisfaction related to Herzberg's theory

Almost none of the instruments discussed prior to Section 2.3.3 were developed in the light of Hertzberg's (1959) two-factor theory of motivation, despite its enduring credibility as a motivational model (see Appendix 2.7). Zhang and von Dran's (2000) model of website design parallels Herzberg's two-factor theory of motivation (see Section 2.3.3 above). However, Herzberg (1968) discusses *job satisfaction*, not satisfaction with a *tool of the trade.* When it comes to the latter, satisfaction is unlikely to involve anything but hygiene factors as soon as a user is experienced with it. This explains one of their own findings; that their factors of *motivation* become *hygiene factors* with the passage of time and growth of experience. The present study finds the attempt to align web site customer satisfaction with Herzberg's theory as positive, but maintains that Herzberg intended job satisfaction rather than satisfaction with a tool of the trade, as websites usually tend to be.

What is significant about Cheung and Lee's (2005) instrument is that they also attempted to align it with Herzberg's theory. They note,

> "we can also classify our web attributes into utility-preserving (hygiene) factors or utility-enhancing (motivation) factors",

after Herzberg. However, with the exception of this instrument and the other two discussed in Section 2.3.3, the use of Herzberg's theory in information systems research in recent times is evidently sparse (see Appendix 2.7, Table 37).

The present study has some difficulty with Herzberg's theory, if it is applied to user satisfaction models as just described. Motivators tend to be *expectations* of satiation of needs (Maslow, 1964), while user satisfaction consists of those factors which are present *after* the user has had some experience of using the system (see Section 2.3). The present study thus concluded that satisfying factors are almost synonymous with hygiene factors, the only difference being that satisfiers apply to the usage of the system, while hygiene factors apply to a wider job context. As mentioned above, Cheung and Lee (2005) found little evidence of asymmetric differences between the positive and negative ratings of the factors tested. This suggests, as in the case of McKinney et al.'s (2002) study, that some factors applied to user satisfaction in the past probably also apply to newer technologies, such as web sites and e-portals.

Cheung and Lee's (2005) instrument (see Appendix 2.6) remains a list of predetermined factors. This means that, apart from their failure to demonstrate asymmetry of impact as discussed above (see Section 2.3.3), some criticisms leveled previously against factor-based instruments must apply to this one (see Section 2.3.1.1); that is, that it may become dated with the advent of new technology. Finally, like all the other factor-based instruments, it is difficult to justify as a *repeated* measure of satisfaction (see Section 2.3.1.1). However, Cheung and Lee (2005) did align their instrument to Herzberg's theory, which adds to its credibility (see Section 2.3.3).

Mullany's (1989) R-Score instrument (see Section 2.3.3 and Appendix 2.4) has the advantage, unlike any of the others described, that it is robust to changes in job context, for example, changes in IT. In reality, this instrument measures user complaint and the study deduces that this is a reasonable surrogate measure of the user's resistance to the system in question. In other words, it simply observes users *in the process of complaining*, whatever the technical nature of the system. Mullany (1989) justified his method of measurement in terms of previous literary studies. For example, the study by Markus (1983) notes that unfair complaints are identified as virtually synonymous with user resistance. Mullany (2001) addressed two criticisms of the R-Score method; namely, that:

1) it may be highly associated with the cognitive style of the interviewer (Kirton, 1989); and
2) at an interview, the user might forget certain crucial problems which had been experienced (Kirton, 1989).

Posit 1) above Mullany refuted on the grounds that the same person did all the interviewing in the former study. However, in the present study, limitations of the author's time meant that data collection by more than one person had to take place, making Posit 1) salient. Hence the sensitivity of the technique to the contaminating influences of different personalities required reconsideration. Ultimately, the insensitivity of the R-Score technique to the cognitive style of the data collector was demonstrated empirically. For details, see Chapter 4, Section 4.3.5.

Posit 2) Mullany dismissed as of limited impact, since the object of the R-Score method was to observe the user *in the process of complaining*, without much concern over what they complained of. Hirschheim and Newman (1988) and Markus (1983) agree that unfair criticism of a system is a resistance-related behaviour. Consequently, it was argued, the resistant user is quite capable of exaggerating or even inventing problems, making the issue of those (s)he may have forgotten irrelevant. However, a limitation was conceded, namely, that there are covert forms of resistance, such as absenteeism and withdrawal, which are not necessarily related to overt complaints.

Kirton's 1999 and 2003 citations of Mullany's study gives credibility to the resistance measure he employed as a viable measure of user resistance. However, one criticism remains, in that Mullany's (1989, 2001) studies made no rigorous effort (beyond discussion) to establish a link between user resistance and user complaining behaviour. It also did not appear to consider complaints that arose through reasons other than unsatisfactory experience, but assumed rather resistant users will complain about *anything* associated with their job context. Mullany's R-Score is the sum of the weighted ratings of missing or inadequate hygiene factors (after Herzberg), as identified by the user. As discussed in Chapter 3, Section 3.3.1.3, the link established by Herzberg between hygiene factors and complaints (see Appendix 2.7) made Mullany's R-Score a suitable basis for a new approach to measuring user dissatisfaction, and hence user satisfaction as it's opposite (see also Chapter 4, Sections 4.3.6, 4.3.7 and 4.3.8). The present study remained aware that satisfaction and dissatisfaction are not necessarily measurable antipodes. In the light of

Herzberg's theory (see Appendix 2.7) this is definitely not the case, since Herzberg related satisfaction to motivators. It also would not be true if the asymmetry predicted by scholars such as Cheung and Lee (2005) is correct. Before any satisfaction instrument based on measures of dissatisfaction (R-Score) could be accepted, therefore, these issues would require addressing.

2.4 Research questions

2.4.1 Measuring changes in user satisfaction over time

No empirical studies were found which show how user satisfaction with a system or any related elements, change with time. As discussed previously, none of the existing factor-based instruments was found to be suitable for this on the grounds of attrition (see Section 2.3.1.1). Mullany's (1989) R-Score has the ability to diarise a user's views of system problems (see Section 2.3.3) and is also based on Herzberg's theory: a sound psychological basis, with wide acceptance (see Appendix 2.7). It also is unaffected by contextual changes such as changes in technology and was thus considered a potential basis for the development of a new instrument for measuring user satisfaction. However, the link between user resistance (or at least, user complaining behaviour) and user satisfaction was far from proven. Despite this, the System Satisfaction Schedule (SSS), based on Mullany's (1989) R-Score with its associated satisfaction S-statistic, was constructed and pilot-tested as part of the development of the research methodology (see Chapter 4, Sections 4.3.6, 4.3.7 and 4.3.8). These exposed a whole new area of research into how user satisfaction evolves over at least a significant part of the associated systems' life cycle. The first research question was thus:

How, in general, does user satisfaction change with time?

2.4.2 The impact of the analyst-user cognitive gap on overall system satisfaction

If, as claimed by Mullany's (1989) study, a positive association exists between user complaints and the analyst-user cognitive differential, then it follows that a negative association should exist between a user's overall satisfaction with a system and the number and intensity of the complaints received. Hence:

Does the cognitive differential between analysts and users (Kirton's (1999) 'cognitive gap') yield advance predictions of overall user satisfaction with a given system?

2.4.3 The impact of cognitive style on system evolution

Mullany's (1989, 2001) studies suggest, inter alia, that matching analysts to users of similar cognitive style will reduce dissonance. This was based on Kirton's (1976) premise that persons of opposite cognitive style tend to exhibit dissonance and may require mid-scorers to form bridges between them for successful work team outcomes. However, there may well be hidden implications in doing this. One might find, for instance, that adaptive analysts with adaptive users would develop a system, which, while thoroughly designed, would be of too limited a scope to be more than a slightly modified form of the old system. The research question suggested by this, was:

What new rules for system development would descend from cognitive style and it's measurement? For example, do new rules emerge for IS team choice based on the cognitive styles of individual users and analysts?

2.4.4 User's changing perceptions of problems over time

As described in Section 2.4.1, no empirical studies could be found which show how user satisfaction with a system or any related elements, change with time. However, where the associated research question of that section considers systems as a whole, this section focuses on the changing perceptions of individual problems during system development and evolution. Research Question 1 in Section 2.4.1 explores this question for systems as a whole. However, little was known as to how a user's perception of an individual problem is likely to change as (s)he becomes more accustomed to the system. If any perceived problem is not solved by technical means, then the user may develop coping skills of avoidance or working around the problem. Significant investigations into this were not found in scholarly IS literature. The associated research question was thus,

How does the perceived severity of system problems change with time?

2.5 Summary of Chapter 2

The main aim of this study was to examine the impact of the user-analyst cognitive style differential on user satisfaction during information systems' life-cycles. This was motivated by a desire to extend Mullany's (1989, 2001) studies; the low overheads required to administer some cognitive style tests; the lack of significant IS studies involving cognitive style; and the recognition by several scholars that user satisfaction is a significant ingredient of system success (see Table 8).

In the light of the above, three categories of literature were surveyed:

- The meaning of the terms 'cognition' and 'cognitive' as used by human science researchers since the mid twentieth century;
- The emergent meaning and measures of cognitive style; and
- IS user satisfaction, its significance and measurement.

The present study identified two gaps in scholarly IS literature:

- It found no recent enquiries into the relationship between user satisfaction and the cognitive styles of those participating in system development; and
- The patterns and principles inherent in the changes in user satisfaction over system usage time were underrepresented.

The chapter first discussed the literature in the general areas of *cognition* and *cognitive theory* and the emergent measures of *cognitive style*. The conclusion was reached that of all the instruments in current use to measure *cognitive style*, the KAI was a strong contender as the most suited to this study. This follows first, from its adherence to a simple, yet credible definition of cognitive problem-solving style in terms of Adaption-Innovation Theory (see Section 2.2.4.1). Second, if one were to assume the success of the present study, the low costs and time-overheads of the KAI's administration mean that it can be recommended to the IS industry as a low-cost tool for assisting with IS team choice. Finally, the KAI does have a record of credibility in modern scholarly literature, independent of Kirton or his organisation (see Sections 2.2.4, 2.2.4.1 and Table 7).

The preceding comments do not mean that weaknesses in the instrument design could not be identified (see Section 2.2.4.1). Any such weaknesses which could cast doubt on the results would need to be adequately addressed in the research design. For example, any belief that the KAI was a second-rate instrument (see Section 2.2.4.1) could be countered by a brief, verbal description of the background to the instrument, its eminence and its current popularity among researchers. Also, helping respondents to avoid errors in completing the KAI form, such as the positioning of their crosses, was an issue (see Section 2.2.4.1). It was thus assumed that the KAI would be best completed under conditions where the data-gatherer could check through the completed instrument and query suspect entries with the respondent directly, prior to scoring.

The chapter then discussed the significance and measure of user satisfaction in the relevant IS literature. The conclusion was reached that none of these is suitable for repeated measures of satisfaction with the same user over time, as errors of attrition would almost certainly contaminate the results. Furthermore, all but three (Mullany, 1989, Zhang and von Dran, 2000, and Cheung and Lee, 2005), were developed without much consideration of Herzberg's two-factor theory of motivation, or for that matter other underpinning theories (see Appendix 2.7 and Sections 2.3.4 and 2.3.4.1).

Finally, based on the discussion of the literature surveyed, the Chapter raises new research questions, which form the basis of this study, as follows:

1) How, in general, does a user's satisfaction with a system change over time? (see Section 2.4.1).
2) Does the cognitive differential between analysts and users (Kirton's (1999) 'cognitive gap') yield advance predictions of overall user satisfaction with a given system? (Section 2.4.2)
3) What new rules for system development would descend from cognitive style and its measurement? For example, do new rules emerge for IS team choice based on the cognitive styles of individual users and analysts? (see Section 2.4.3)

4) How does the user's perceived severity of system problems change with time? (see Section 2.4.4).

To the best of the author's knowledge and belief no prior study exists which substantially tackles any of the above questions, making this study a significant contribution to knowledge in the fields of information systems usage, development and evolution.

Chapter 3

Development of hypotheses

3.1 Introduction

To study the research questions as proposed by Chapter 2 (see Section 2.5), two basic measures were required; one of cognitive problem-solving style, and the other of information system user satisfaction. In section 3.2 the unit of research is defined as instances of a single user in association with a single system. Section 3.3 outlines the models which underpin the hypotheses together with the hypotheses themselves. For a listing of the latter, see Tables 16(a) to 16(d).

Regarding the development of an instrument to measure user satisfaction, a model of user satisfaction, based on Herzberg's two-factor theory of motivation, was first developed (see Section 3.3.1). The assumptions upon which this model is based, are justified and discussed. A case is made that a suitable instrument to measure user satisfaction as the weighted sum of the user's complaints, is both feasible and valid. This is based on the links between user satisfaction and experience of the system, and between user satisfaction and Herzberg's hygiene factors, established respectively in Sections 3.3.1.1 and 3.3.1.2. There it is argued that overall satisfaction with a system is a lack of dissatisfaction. This is in line with Herzberg's theory, not withstanding some prior criticism of the latter (see Chapter 2, Section 2.3.3). Section 3.3.1.3 discusses Mullany's (1989) measure of user resistance, by way of recorded complaints, identified by users, and then weighted in terms of their perceived importance. This is established as a viable means of finding inadequately addressed hygiene factors (Herzberg, 1968) and hence a means of measuring user dissatisfaction. The present study argues that the measure of dissatisfaction, as the weighted sum of a user's complaints can be reversed algebraically to provide a measure of user satisfaction. This follows from the establishment of the link between user satisfaction and user hygiene (see Sections 3.3.1.2). Section 3.3.1 concludes with the claim that:

> ***The degree to which a user satisfier is unaddressed can be identified by the rated intensity of a complaint made by the user. The weighted sums of a user's complaints in respect of a system is a valid measure of overall dissatisfaction, and also of its reverse, overall satisfaction.***
>
> (see Section 3.3.1.3.)

The construction of the associated instrument, called the System Satisfaction Schedule (SSS), is described in Chapter 4, Sections 4.3.6, 4.3.7 and 4.3.8. The satisfaction score (S-Score) or S statistic are equivalent names given to the single-value output from the SSS (see Section 3.3.1.3).

As is evident from Section 3.3.2, the present study adopted Kirton's Adaption-Innovation Theory and its attendant instrument, the Kirton Adaption-Innovation Inventory (KAI) (see Chapter 2, Section 2.2.4.1). General hypotheses emanating from the definition of user satisfaction (S) and its relation to cognitive style as defined in Adaption-Innovation Theory, are then proposed and discussed in Section 3.3.2.1.

Section 3.4 identifies the possibility of studying the way in which the user perception of system problems may decrease with time. Simple mathematical trend models for the change in perceived problem severity over time are explored.

3.2 The User-System (US) entity

As data for one user could be collected for more than one system (s)he uses and a given system could interact with more than one participating user, the relationship between users and systems is many-to-many. The present study coined the term User-System (US) for these entities. In other words, this study essayed to collected data from a *sample* of USs so as to make inferences about the *population* of USs (for a detailed discussion of the research population and sample, see Chapter 4, Section 4.2). Strictly speaking, it *can* be argued that the elements of the research are user-analyst-systems, but this seemed unnecessarily complex. A US was defined as an entity which terminated either if the analyst changed, or usage by the same user ceased (for the formal definition of the term *analyst*, see Chapter 2, Section 2.1).

Insofar as an information system is an

> "organized combination of people, hardware, software, communication networks and data resources" (O'Brien, 2003),

a US was assumed to be a subset of an information system.

As discussed in Chapter 2 (see Section 2.2.4), the Kirton Adaption-Innovation Inventory (KAI) was identified as a viable option to measure individuals' cognitive styles, and was adopted by this study (see Chapter 4, Section 4.3.1). For user satisfaction, an instrument based on Mullany's (1989) resistance-score (R-Score) was developed. For details of this, see Chapter 4, Sections 4.3.6, 4.3.7 and 4.3.8.

3.3 Theoretical models and the hypotheses they support

The models which underpin the hypotheses are:

- The model of user satisfaction developed;
- Trends in user satisfaction over time; and
- The model of cognitive style used.

Each is now dealt with in turn (Sections 3.3.1, 3.3.1.4 and 3.3.2 respectively).

3.3.1 The model of user satisfaction developed, together with the attendant hypotheses

The model of user satisfaction employed by this study, contains three basic assumptions as follows:

1) ***Users must have some experience of a system relevant to their usage before they can assess their satisfaction or dissatisfaction with the system;***
2) ***User satisfiers are synonymous with Herzberg's hygiene factors, not with motivators; and***
3) ***The degree to which a user satisfier (as defined in 2 above) is unaddressed can be measured by the rated intensity of a complaint made by the user. The weighted sums of a user's rated complaints in respect of a system is a valid measure of overall dissatisfaction, and also of its reverse, overall satisfaction.***

The justification of these assumptions follows.

3.3.1.1 The link between user satisfaction and experience of the system

As discussed in Chapter 2 (see Section 2.3) ***User satisfaction*** **implies a summary of those factors in a user's experience of a system which satiate his/her job needs *after* some experience of using it.** From this follows the first basic assumption of this satisfaction model:

> ***Users must have some experience of a system relevant to their usage before they can assess their satisfaction or dissatisfaction with the system.***

3.3.1.2 The link between user satisfaction and Herzber's hygiene factors

Herzberg (1968), in a literature survey and discussion of employee motivation, equates job satisfaction to motivation. He notes that

> "the factors involved in producing job satisfaction (and motivation) are separate and distinct from the factors that lead to job dissatisfaction."

He continues that,

> "Since separate factors need to be considered, depending on whether job satisfaction or job dissatisfaction is being examined, it follows that these two feelings are not opposites of each other. The opposite of job satisfaction is not job dissatisfaction but, rather, no job satisfaction; and similarly, the opposite of job dissatisfaction is not job satisfaction, but no job dissatisfaction." (Herzberg, 1968).

As it is difficult to see how a person could be content in their job unless the job provides at least some ongoing motivation, this study accepted Herzberg's posit of job satisfaction as a consequence of motivation, *a priori*. However, one should note that Herzberg does not equate *job satisfaction* to *satisfaction with a tool of the trade*, such as a computer-based system. For the latter, the question becomes, which type of factor is user satisfaction: a motivator (or group of motivators), a hygiene factor (or group of hygiene factors), or some combination of the two? (For further details of Herzberg's two factor theory of motivation, see Appendix 2.7.) This study thus sought literature in the allied field of *customer satisfaction* to shed light on the matter.

A model used in McKinney et al.'s (2002) study of user web site satisfaction was that of Oliver (1980) (see Chapter 2, Section 2.3.3). The latter proposes an *expectation-disconfirmation* model of customer satisfaction. According to this, customers develop an expectation of a product which is either confirmed or disconfirmed by their actual experience of the product. Disconfirmation can be either positive or negative and will, he claims, affect the decision to purchase the same product again. If the same model were applied to the user's expectations and experiences of a system, user satisfaction would reduce to a comparison between the two. In compliance with Herzberg's (1959) theory, expectations, as promises and threats, motivate the user to use or not to use the system. They thus boil down to motivators. All other factors will correspond to hygiene factors, which are either present, absent or insufficiently fulfilled to bring about complete satisfaction.

The application of Oliver's (1980) model to user satisfaction thus implies that once a user becomes completely knowledgeable on how to use a system, the only remaining factors affecting satisfaction will be hygiene factors. This follows from the fact that the user's expectations are replaced by user know-how, and thus the expectations no longer motivate. In other words, as soon as a user is using a system as a matter of course, user satisfaction is a matter of addressing deficits in hygiene. This suggestion is supported by Zhang and von Dran's (2000) empirical study of user satisfaction with web sites (see Chapter 2, Section 2.3.3). Herzberg (1966) established a link between low hygiene and complaints (see Appendix 2.7), suggesting that user satisfaction is highest when the user makes the fewest complaints of the lowest intensity possible. The construct, *satisfaction with a tool of the trade*, then, is seen to apply to *an absence of dissatisfaction only*, especially if the user is well aware of how that tool should function, or has expectations based on experience of how it should function.

In the light of the above, the present study explored the possibility that most of the factors used in the most popular factor-based user satisfaction instruments are hygiene factors. To qualify as hygiene, a factor must be descriptive of the *job context* rather than *job content* (see Appendix 2.7). In other words, it must be able *potentially* to apply to more than one system which the user employs and hence is part of their work environment. The first test was an examination to see if each factor could apply to more than one system or one type of system. If so, it is a measure of the work environment and job context, and hence is a hygiene factor.

The second test was based on the expected dissatisfaction which a user might feel if they did not give the most positive rating possible for a given factor. For example, consider the first item of Doll and Torkzadeh's (1988) End-User Computing Satisfaction Instrument (see Appendix 2.5):

	Almost always	**Most of the time**	**About half of the time**	**Some of the time**	**Almost never**
Does the system provide the precise information you need?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**

If a user respondent rates this factor as less than 5, (s)he is making it clear that at least on some occasions the system does not supply the precise information (s)he requires, and on such occasions at least some level of dissatisfaction is felt with the precision of the information. In the light of Herzberg's (1968) study, as soon as a phenomenon is found to cause dissatisfaction and complaints, it signifies an incompletely addressed hygiene factor. The second test thus reduced to showing how each factor over a wide range of factor-based instruments could cause dissatisfaction if not given the most positive rating. The instruments and factors subjected to these tests are given in Table 13, together with the test results. As is clear from this, *all* factors listed were found to be hygiene factors. This means that the most used instruments of the factor-based variety essentially measure user satisfaction as the presence of hygiene factors, and dissatisfaction as the extent to which these are not fulfilled.

Table 13: Evidence that factors from popular user satisfaction instruments are hygiene factors
(Table occupies pages 112 to 115)

BAILEY & PEARSON (1983) 5 most significant factors				
FACTOR	**TEST 1**	**TEST 2**	**FACTOR IS HYGIENE: CONFIRMATION**	
	Could this factor apply to more than one system used by the respondent, thus indicating that it is a hygiene factor?	**If the user respondent does not give the most positive rating, then, at least on occasion, dissatisfaction would be caused by:**	**TEST 1**	**TEST 2**
System accuracy	**yes**	inaccuracies in the output.	✓	✓
System reliability	**yes**	the system not functioning when needed.	✓	✓
System timeliness	**yes**	output not being available when required.	✓	✓
Relevancy of the system output	**yes**	output not relevant to the job content.	✓	✓
Confidence in the system	**yes**	the system letting the user down (falling over).	✓	✓

OLSON, IVES & BAROUDI (1983), in BAROUDI & ORLIKOWSKI (1988) User Information Satisfaction Short form				
FACTOR	**TEST 1**	**TEST 2**	**FACTOR IS HYGIENE: CONFIRMATION**	
	Could this factor apply to more than one system used by the respondent, thus indicating that it is a hygiene factor?	**If the user respondent does not give the most positive rating, then, at least on occasion, dissatisfaction would be caused by:**	**TEST 1**	**TEST 2**
Relationship with the Electronic Data Processing staff	**yes**	rudeness or lack of cooperation by an EDP professional.	✓	✓
Processing of requests for changes to existing systems	**yes**	the unavailability of the updated system as soon as the user would like.	✓	✓
Degree of EDP training provided to users	**yes**	a visible lack of user knowledge.	✓	✓

Table 13: ***continued from Page 112***
(Table occupies pages 112 to 115)

OLSON, IVES & BAROUDI (1983) User Information Satisfaction Short form *continued*				
FACTOR	**TEST 1**	**TEST 2**	**FACTOR IS HYGIENE: CONFIRMATION**	
	Could this factor apply to more than one system used by the respondent, thus indicating that it is a hygiene factor?	**If the user respondent does not give the most positive rating, then, at least on occasion, dissatisfaction would be caused by:**	**TEST 1**	**TEST 2**
Users' understanding of systems	**yes**	a visible lack of the user's system knowledge.	✓	✓
Users' feelings of participation	**yes**	exclusion of the user from system decision-making.	✓	✓
Attitude of the EDP staff	**yes**	rudeness or lack of cooperation by an EDP professional.	✓	✓
Reliability of output information	**yes**	a vital piece of information not reaching the user.	✓	✓
Relevancy of output information (to intended function)	**yes**	output which is not relevant to the user's job content.	✓	✓
Accuracy of output information	**yes**	inaccuracies in the output.	✓	✓
Precision of output information	**yes**	output which is either too spuriously accurate or imprecise.	✓	✓
Communication with EDP staff	**yes**	rudeness or lack of cooperation by an EDP professional.	✓	✓
Time required for new systems development	**yes**	the unavailability of the updated system as soon as the user would like.	✓	✓
Completeness of the output information	**yes**	output which doesn't contain all the information the user requires.	✓	✓

Table 13: ***continued from Page 113***
(Table occupies pages 112 to 115)

DOLL & TORKZADEH (1988) **End-User Computing Satisfaction Instrument**				
FACTOR	**TEST 1**	**TEST 2**	**FACTOR IS HYGIENE: CONFIRMATION**	
	Could this factor apply to more than one system used by the respondent, thus indicating that it is a hygiene factor?	**If the user respondent does not give the most positive rating, then, at least on occasion, dissatisfaction would be caused by:**	**TEST 1**	**TEST 2**
Does the system provide the precise information you need?	**yes**	output which is either too spuriously accurate or imprecise.	✓	✓
Does the information content meet your needs?	**yes**	a lack of information required.	✓	✓
Does the system provide reports that seem to be just about exactly what you need?	**yes**	poor or confusing layout of the report(s).	✓	✓
Does the system provide sufficient information?	**yes**	a lack of some of the information required.	✓	✓
Is the system accurate?	**yes**	inaccuracies in the output.	✓	✓
Are you satisfied with the accuracy of the system?	**yes**	inaccuracies in the output.	✓	✓
Do you think that the output is presented in a useful format?	**yes**	poor or confusing layout of report(s).	✓	✓
Is the information clear?	**yes**	poor or confusing layout of report(s).	✓	✓
Is the system user-friendly?	**yes**	confusion in the screen layout.	✓	✓
Is the system easy to use?	**yes**	uncertainty on how to proceed when using the system.	✓	✓
Do you get the information you need in time?	**yes**	a lack of information required.	✓	✓
Does the system provide up-to-date information?	**yes**	a lack of up-to-date information required.	✓	✓

Table 13: ***continued from Page 114***
(Table occupies pages 112 to 115)

CHEUNG & LEE (2005), building on the McKINNEY/YOON/ZAHEDI MODEL (2002) **Asymmetric Information Quality - / System Quality - Model of Web Site (E-Portal) User Satisfaction**				
	TEST 1	**TEST 2**	**FACTOR HYGIENE: CONFIRMATION**	
INFORMATION QUALITY FACTORS	**Could this factor apply to more than one system / web site used by the respondent, thus indicating that it is a hygiene factor or related to an unfulfilled hygiene factor?**	**If the user respondent does not give the most positive / least negative rating, then, at least on occasion, dissatisfaction would be caused by:**	**TEST1**	**TEST2**
Understandability: ***Positive attributes***: Clear in meaning, Easy to understand, Easy to read.	**yes**	the user not knowing how to proceed because (s)he can't make out directions given by the site.	✓	✓
Understandability: ***Negative attributes***: Not clear in meaning, Not easy to understand, Not easy to read.	**yes**		✓	✓
Reliability: ***Positive attributes***: Trustworthy, Accurate, Credible.	**yes**	the user finds false information on the website, so feels (s)he can't trust other information given.		
Reliability: ***Negative attributes***: Not trustworthy, Not accurate, Not credible.	**yes**		✓	✓
Usefulness: ***Positive attributes***: Informative, Valuable	**yes**	the user not finding all the information (s)he wants or needs.	✓	✓
Usefulness: ***Negative attributes***: Not informative, Not valuable	**yes**		✓	✓
SYSTEM QUALITY FACTORS	**TEST 1**	**TEST 2**	**FACTOR HYGIENE: CONFIRMATION**	
Access: ***Positive attributes*****:** Responsive, Quick loads	**yes**	the user waiting a long time for urgent information.	✓	✓
Access: ***Positive attributes*****:** Not responsive, Loads take too long	**yes**		✓	✓
Usability: ***Positive attributes*****:** Simple layout, Easy to use, Well organised	**yes**	the user not knowing how to proceed because (s)he can't make out directions given by the site.	✓	✓
Usability: ***Negative attributes*****:** Complex layout, Difficult to use, Poorly organised	**yes**		✓	✓
Navigation: ***Positive attributes*****:** Easy to go back and forth, Few clicks	**yes**	the user being unable to retrieve the previous page by a single click of the back-arrow button and without directions on what to do about it.	✓	✓
Navigation: ***Positive attributes*****:** Difficult to go back and forth, Too many clicks required	**yes**		✓	✓

Cheung and Lee's (2005) study of users' satisfaction with e-portals (see Chapter 2, Section 2.3.3), makes use of a factor-based instrument with seven-point scales (see Appendix 2.6). This study describes satisfaction factors as *asymmetric*, meaning that the impact of positive and negative ratings of the same factor are different and should be processed differently. However, they found that while the internal reliability of their instrument was high, their hypotheses tested inconclusively; that is, their study could not show strongly significant asymmetric differences between the positive and negative ratings of the factors tested (Cheung and Lee, 2005). In other words, their instrument boiled down to another factor-based questionnaire, where the factors turn out to be hygiene factors (see Table 13).

The above discussion demonstrates that what IS researchers have hitherto called *user satisfaction factors*, Herzberg's theory classifies as *hygiene factors*. This study therefore coined the term *user satisfier* or *satisfier* for a hygiene factor in the context of system usage and development. This gives the second assumption of the user satisfaction model used in this study:

> ***User satisfiers are synonymous with Herzberg's hygiene factors, <u>not</u> with motivators*** (see Appendix 2.7 for details of Herzberg's theory).

A further point needs consideration in the light of this. If the factors which are exhibited in Table 13 are hygiene factors, then it follows that they are *not* motivators (see Appendix 2.7). In other words, if Herzberg's theory holds credence, then what all prior factor-based instruments tacitly conjecture is that satisfaction is a *demotivation-avoidance* phenomenon, not a motivational one. It also suggests that if one records users' expressions of dissatisfaction only, satisfaction can be validly measured as the absence of user complaints.

3.3.1.3 Factors identified by users

Mullany (1989, 2001) developed a method of measuring user resistance, based on Herzberg's hygiene factors, by way of semi-structuring unstructured responses (for details, see Chapter 2, Section 2.3.3, and Appendix 2.4). As discussed in Chapter 2, the user was effectively asked to make complaints, in confidence, against the system and/or its manner of implementation. (S)he was then requested to rate the severity of each complaint on a seven-point scale (with 7 representing the most severe weighting). The sum of severities of all the complaints measured was taken as his/her resistance score or R-Score (see Appendix 2.4). This procedure agrees with Herzberg's scenarios (see Appendix 2.7) in which complaints are noted as symptoms of inadequately addressed or missing hygiene factors. As discussed in Section 3.3.1.2 above, the factor-based instruments really measure user satisfaction as the presence of hygiene factors, and dissatisfaction as the extent to which these are not addressed. Optimum satisfaction thus implies zero complaints. Any other rating would imply less than complete satisfaction. This means that the R-Score measures satisfaction as the proximity to zero, and dissatisfaction as a deviation from zero. One then obtains the third assumption of the user satisfaction model used in this study:

> ***The degree to which a user satisfier is unaddressed can be identified by the rated intensity of a complaint made by the user. The weighted sums of a user's complaints in respect of a system is a valid measure of overall dissatisfaction as a deviation from zero, and hence satisfaction as the sum's <u>proximity to zero</u>.***

The three assumptions justified above form the corner stone of the method used in this study to measure user satisfaction and to develop an instrument for so doing. These aspects are discussed further in Chapter 4 (see Sections 4.3.2 to 4.3.8). In the interim is will be assumed that satisfaction can be measured by an approach analogous to Mullany's (1989) R-Score, denoted by the statistic S. It was designed so that the larger S's algebraic value, the greater the measured satisfaction of the user. The conversion of the R-Score measure into a viable measure of S is dealt with in detail in Chapter 4, Sections 4.3.2 to 4.3.8.

3.3.1.4 The research question based on the measure of user satisfaction over time

The first research question was:

How, in general, does a user's satisfaction with a system change over time?

(see Chapter 2, Section 2.5).

Conjectures relating to the nature and shape of the user-satisfaction time series were speculative as no studies were found to base them on. However, if the first assumption articulated in Section 3.3.1 above is accepted, that

> "users must have experienced at least some aspects of a system relevant to their usage before they can assess their satisfaction or dissatisfaction with the system",

and one adds the assumption that experience increases with system usage, then satisfaction should rise with the increase in usage. This implies that:

$H_{1(a)}$:	During the life of a US, user satisfaction will generally rise with time as the user gains experience with the system.

No grounds for suggesting a particular curve shape, or rate of change could be deduced from the literature surveyed, so this study left the exact nature and shape of the satisfaction time-series to be a matter of discovery. The findings are recorded in Section 5.3 of Chapter 5.

3.3.2 The model of cognitive style used

The cognitive style model used in this research is that of Kirton (1976, 2004) and the Kirton Adaption-innovation Inventory (KAI). For details and justification, see Chapter 2, Section 2.2.4. As there discussed, this approach to the measure of cognitive style grew out of previous efforts to develop continuous, bipolar scales. A limitation of all the other instruments found was their low construct validity: that is, unsatisfactory arguments for the extremes measured. This was earlier put down to a continued failure to separate out *cognitive style* and *cognitive level* as Kirton (2004) agrees.

As discussed in Chapter 2, Section 2.2.4, Kirton (1999) proposes two main categories of problem-solver: *Adaptive* and *Innovative*.

The attendant instrument, the KAI, has the added advantage of providing a single, bipolar scale for cognitive style measurement, thus making it a simple and inexpensive instrument to administer and to analyze statistically. Please refer to Chapter 2, Table 5(a) for a selection of KAI internal reliabilities for given samples and to Chapter 2, Table 5(b) for a selection of KAI test-retest reliabilities. As will be seen from these, the KAI is a reliable instrument with the attendant coefficients generally being above 0.8. Priddey and Williams (2000) claim that the KAI has been a measure that has attracted attention in areas such as team building, conflict resolution, cross-cultural studies and education. This opinion was typical of others found in scholarly literature, and motivated this study further to use the KAI as the measure of individuals' cognitive styles.

3.3.2.1 Expected hypotheses emanating from Adaption-Innovation Theory and its relationship with user satisfaction

Where a user and analyst are of similar cognitive style, one would expect stress to be minimized between the two as each could follow his/her preferred problem-solving style within the dyadic couple (Kirton, 1976, 1999, and Mullany, 1989). However, if they differ in cognitive style, one would expect greater dissonance. Both would be expected to exhibit greater stress than in the former case, since to produce a joint solution with the other, each would feel the need to relinquish their preferred problem-solving style, at least for some of the time (Kirton, 1999). When one considers that a user and analyst may need to work closely, sometimes over years, for the continued update and maintenance of a system, one would expect the user to be more stressed if the analyst is of dissimilar, rather than of similar cognitive style. Once one has a satisfactory measure of stress, one can hypothesize that user stress and the analyst-user cognitive style differential are at least associated, if not correlated. Low stress, being part of a worker's job context, is a hygiene factor (see Appendix 2.7). Hence high stress would be expected to demotivate a user and result in their complaining (Herzberg, 1968). Such complaints are likely to be more intense than complaints made under the lower stress situation. Table 14 makes these expectations clear.

Table 14: Expected outcomes for users and systems analysts of various cognitive styles

	Adaptive Analyst	**Innovative Analyst**
Adaptive User	Low stress. Few complaints. Not very intense complaints.	High stress. Lots of complaints. Intense complaints.
Innovative User	High stress. Lots of complaints. Intense complaints.	Low stress. Few complaints. Not very intense complaints.

(see Appendix 2.7)

3.3.2.2 Simple links between the cognitive gap and user satisfaction

It follows from the discussion above, that the larger the difference in cognitive style between team members, the more dissonance tends to exist between them. If such a team consists of a user and a systems analyst, then it follows that the greater their cognitive gap, the greater the level of dissonance between them. Additionally, Mullany (1989) suggested that in general, the greater the cognitive gap, the less credibility the analyst's system tends to have with the user. Hence one would expect an association between the analyst/user cognitive gap and any factors which can be taken as surrogates of overall user satisfaction/dissatisfaction.

The second research question given in Chapter 2 was:

> ***Does the cognitive differential between analysts and users (Kirton's (1999) 'cognitive gap') yield advance predictions of overall user satisfaction with a given system?*** (see Section 2.5)

That there is a link between the analyst-user cognitive differential (as measured using the KAI) and the number and intensity of complaints received was demonstrated by Mullany's (1989) study as discussed above. The suggested link is also consistent with Herzberg's theory of motivation, in that the latter establishes a link between dissatisfaction and employee complaints (see Appendix 2.7). Taken together, these imply that the greater the cognitive differential, the more dissatisfied users will tend to be with the system generated, and that this dissatisfaction can be measured by recording the number and intensities of their complaints. Hence one would expect a *negative* association between the KAI differential and user satisfaction.

However, as the present study intended to measure user satisfaction over time, it had to cater for expected changes in user satisfaction measures over time. Descriptive statistics for overall satisfaction were thus required. The four used are identified and described in Appendix 3.1. They were the *minimum, maximum, median* and *mean* satisfaction (S-Score) readings. One other popular descriptive measure, the *mode*, was not used in this study since not all small samples exhibit modes (Zar, 1999). Based on the former four descriptive statistics, this study identified four corresponding hypotheses $H_{2(a)}$ – $H_{2(d)}$, thus:

$H_{2(a)}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***minimum*** S-Score exhibited by the user during the US's life.

$H_{2(b)}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***maximum*** S-Score exhibited by the user during the US's life.

$H_{2(c)}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***median*** S-Score exhibited by the user during the US's life.

$H_{2(d)}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***mean*** S-Score exhibited by the user during the US's life.

3.3.2.3 Relevancy curves and their relationship with the cognitive gap

The third research question proposed by Chapter 2 was,

> ***What new rules for system development would descend from cognitive style and it's measurement? For example, do new rules emerge for IS team choice based on the cognitive styles of individual users and analysts?***
>
> (see Section 2.5)

This question proposes the possibility of new rules for system development based on cognitive style. As none of the literature surveyed provided a basis, any emergent new rules necessarily became a matter of discovery as much as an application of existing theory. However, the question has at its heart the issue of *how relevant* cognitive style theory is at various stages of the US's life. The next group of hypotheses developed, addresses these issues. For this a means of quantifying *relevance* was required, together with various ways of rating the cognitive differential. A measure of association was used for the former. Of the two measures in common use, the Kendall rank correlation co-efficient (t) was selected in preference to the Spearman r_s (for the justification of this choice, see Appendix 4.1, Section 4.1.8). The Kendall rank correlation co-efficient (t) measures the *association* between the data in a bivariate sample. If two data pairs (x_1, y_1) and (x_2, y_2) are chosen at random from the sample (X, Y), they are said to be *concordant* if:

$$x_1 > x_2 \text{ when } y_1 > y_2.$$

If the converse applies, they are said to be *discordant*. t then is the probability that any two data pairs drawn at random from the sample are concordant *less* the probability that they are discordant, giving:

$$t = P(\text{concordant}) - P(\text{discordant}).$$

t ranges from -l (for perfect negative association) to +1 (for perfect positive association), while the value 0 indicates independence as a zero association (for more detail, see Appendix 4.1, Section 4.1.8).

In terms of the analyst-user cognitive differential (see Section 3.3.2.1), where a user and analyst are of similar cognitive style, one would expect stress to be minimized as each can follow his/her preferred problem-solving style within the US's dyadic couple. However, as discussed in Section 3.3.2.1, if they differ in cognitive style, both would be expected to exhibit greater stress than in the former case. For greater clarity refer to Table 14 above, from which two basic scenarios emerge:

1) If the analyst and user are similar in cognitive style, then their working relationship will tend to be characterized by low stress, few complaints and not very intense complaints. In general, the user would be expected to be more satisfied with the system for longer periods of time, according to the satisfaction model outlined in Section 3.3.1.
2) If, however, the analyst and user differ in cognitive style, then their working relationship will tend to be characterized by high stress, many complaints and intense complaints.

For the calculation of the analyst-user cognitive differential as the difference between the user's and analyst's KAI scores, three mathematically distinct models are possible:

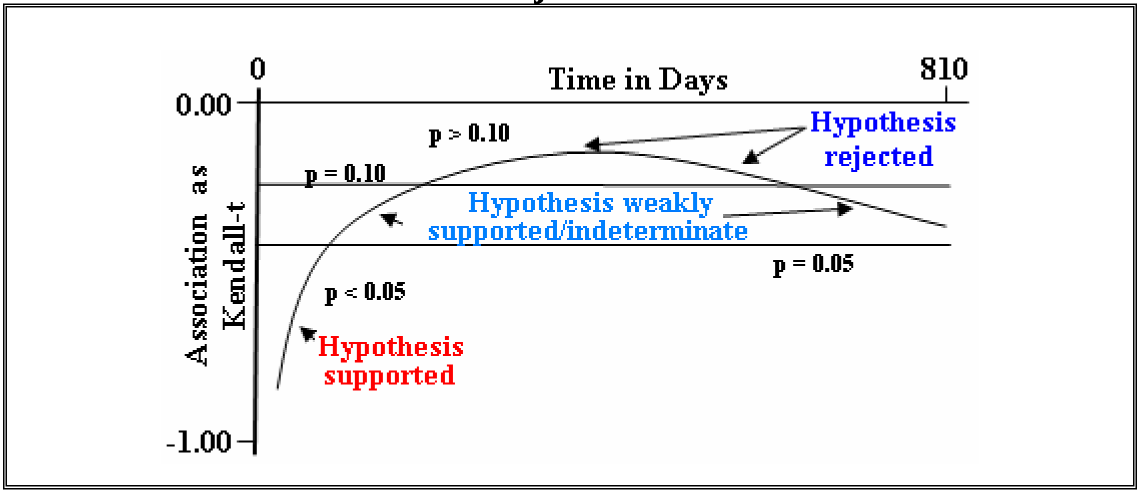
1) The absolute difference between the Analyst's KAI score and the User's;
2) The Analyst's KAI score less the User's (giving signed results); and
3) The User's KAI score less the Analyst's (also giving signed results).

In fact, the first two of these options represent different models with a potentially different impact on user satisfaction measured over time. The third is really just the inverse of the second, so a separate hypothesis based on this model would yield no further information. It was thus not considered further. In the case of model 1, the absolute KAI differential is by definition non-negative so that it ranges from zero upwards. The focus is on the dissatisfaction associated with the cognitive gap. It does not matter which of the user or analyst has the higher KAI score. Model 2, on the other hand, targets impacts imposed by an analyst who is *more innovative* than the user. It may well transpire, for instance, that users (even innovative users) are more satisfied with systems built by adaptive analysts in the early stages of system development since innovators appear

> "insensitive to people, often threatening group cohesion and cooperation."
> (see Kirton, 1999 and Appendix 2.1).

To test speculations based on models 1 and 2, the present study essayed to produce graphs of the varying association over time (as Kendall-t values) between the value of the differential and S, for each cognitive gap model. For the sake of brevity, this study coined the terms *relevance, relevancy* and *relevant* to denote the association between the cognitive differential and the satisfaction measure. In other words, the *larger* and the *more significant* the association at any point in time, the *more relevant* is the cognitive differential model at that time. This enabled an examination as to where during systems' lives the cognitive differential is most relevant, by inferring *when in general* these hypotheses can be accepted, are indeterminate, or can be rejected. For clarity, the type of graph envisaged is illustrated in Figure 3. This shows the plotting of the cognitive style / user satisfaction association on time for a hypothetical sample of USs. The associations are supposedly measured across the sample of USs and are calculated for each day since the initiation of all the attendant systems.

Figure 3: Graph of cognitive/satisfaction association on time for a hypothetical sample of users, illustrating regions where the attendant hypothesis might be accepted, test indeterminate or be rejected.



With reference to Figure 3, taken together with the preceding discussion, the implicit hypothetical cognitive model would be relevant or highly relevant in the region where the curve is below the p = 0.05 significance level line; that is, where the hypothesis receives most support. It would be weakly relevant where the hypothesis is weakly supported between the 0.05 and 0.10 significance levels, and not relevant where the hypothesis is rejected above the 0.10 significance level line (for a discussion of the strength of significance levels, see Appendix 4.1, Section 4.1.2 and Tables 38 and 39).

A different curve, of course, is expected for each of the two cognitive differential models. The hypotheses corresponding to these models are as follows:

$H_{3(a)}$	The absolute cognitive gap, taken as |Analyst's KAI score – User's KAI score| is negatively associated with the S-Score at any given point in time during the US's life.

$H_{3(b)}$	The cognitive gap measured as the Analyst's KAI score less the User's KAI score is negatively associated with the S-Score at any given point in time during the US's life.

For completeness, the study also tested the relevance (as defined above) of the user's KAI by graphing associations between the user's KAI and user satisfaction, on time. This was in an effort to discover whether or not user satisfaction is in part a function of the user's cognitive style. As adaptors tend to become wedded to systems (Kirton, 1984), one might speculate that adaptive users will eventually reach a state of satisfaction with *any* system if they have used it for long enough. In short, as a system ages, adaptive users would be expected to become more satisfied with it. As the most adaptive respondents score towards the bottom end of the KAI scale, one would expect an association between users' KAI measures and users' S-Scores to *rise negatively* during the period of usage. From this the following hypothesis was developed:

$H_{3(c)}$	The user's cognitive style measured as the User's KAI score generally *increases negatively* during the US's life.

As innovators tend to 'rock the boat' (Kirton, 1984), this study argued that innovative analysts would be expected to cause dissonance and hence will generally dissatisfy most users throughout the period of usage. This implies the following:

$H_{3(d)}$	The analyst's cognitive style measured as the Analyst's KAI score is negatively associated with the S-Score at any point in time during the US's life.

It was hoped that new rules for systems development would emanate from an investigation of the hypotheses **$H_{3(a)}$** to **$H_{3(d)}$** and the relevancy graphs, since these were expected to show when, during system evolution, each model would be most salient.

3.4 Trend models for measures of user complaints over time

The fourth research question formulated in Chapter 2 (see Section 2.5) was,

How does the user's perceived severity of system problems change with time?

No prior research was found which shed any precise light on how a user's perception of a system problem changes with time. Since several systems, together with their user-identified problems, were to be studied over several months (see Chapter 4, Section 4.3.9), the opportunity to investigate this was evident. In the absence of any guidance from the scholarly IS, management, educational or psychological literature on the matter, this research resorted to the physical sciences for analogies and models.

Four simple analytic functions, frequently used in time series analysis were selected as candidates for such trends. They were:

- Rectilinear (straight line);
- Quadratic;
- Reciprocal; and
- Exponential decay.

For discussion and mathematical background to these models, refer to Appendix 3.2. These commonly used mathematical functions, together with their generalised mathematical expressions, are given in Table 15. For the mathematical sources and under-pinning, see Appendix 3.2.

Table 15: Summary of analytic functions fitted to perceived problem severities (R)

Function type	**Expression**	**Meanings of variables**	**Description of model**
rectilinear	$R = R_0 + m t$	R_0 = Vertical intercept = R at time t = 0 m = slope, and m < 0 t = time	R falls at a constant rate.
quadratic	$R = a (t - p)^2 + q$	a > 0 p = axis of symmetry q = minimum value t = time	R falls at a decreasing rate to a minimum value.
reciprocal	$R = \frac{k}{t + a} + \ell$	-a = vertical asymptote k = scaling constant ℓ = horizontal asymptote t = time	R decreases inversely as time increases; the longer a problem is experienced, the less severe it will become.
exponential decay	$R = a e^{-kt} + \ell$	a = initial value k = constant of proportionality < 0 ℓ = horizontal asymptote	R decreases at a rate in proportion with its size; the more severe a problem, the more quickly and intensely it will be addressed.

3.4.1 The rectilinear model

According to this model, a value associated with some given phenomenon drops at a constant rate with time (see Table 15 and Appendix 3.2). The attendant hypothesis is:

> **$H_{4(a)}$**: The plot of the perceived severity of a system problem, (R), versus time (t) gives a rectilinear graph with general expression:
>
> $R = R_0 + m t$
>
> where R_0 is the vertical intercept and m is the rate at which perceived problem severity changes.

3.4.2 The quadratic model

If the graph of perceived severity is not rectilinear, then it may either be curvilinear or random (with unexplained variation) or some combination of the two (Berenson and Levine, 1986). The quadratic function can approximate a large number of curves (see Appendix 3.2). This suggested the quadratic model was a plausible option for application to perceived problem severity.

For curve-fitting, the following alternative form of the quadratic function is available, which is more tractable to handle than the previous one:

$$R = a\,(t - p)^2 + q$$

where a is the quadratic coefficient, p is the axis of symmetry and q is the maximum or minimum value (see Table 15 and Appendix 3.2). If a problem's R-Score and time since initiation in days are substituted for R and t and a graph plotted, one may hypothesise that:

> **$H_{4(b)}$**: The plot of the perceived severity of a system problem, (R), versus time (t) gives a quadratic function graph with general expression:
>
> $$R = a\,(t - p)^2 + q$$
>
> where a is the quadratic coefficient (> 0), p is the axis of symmetry and q is the minimum value.

3.4.3 The reciprocal model

This model proposes that the phenomenon under investigation has at its heart an *inverse proportion* (see Appendix 3.2 and Table 15) and that the perceived problem severity generally decreases with time. This implies that the longer a user experiences a problem the less severe its perception will tend to become. This may be either because the user develops coping skills or because the problem is actively addressed and ameliorated. As it is plausible that a user will find a problem to reduce in proportion to the length of time he/she experiences it, this model was also selected for testing. In general a reciprocal function has two asymptotes; one vertical and one horizontal. A general expression for this is:

$$R = \frac{k}{x + a} + \ell$$

where -a is the vertical asymptote, k is a scaling constant and ℓ is the horizontal asymptote. By using the same quantities as before for R and t, the following hypothesis is obtained:

> **$H_{4(c)}$**: The plot of the perceived severity of a system problem, (R), versus time (t) gives a reciprocal function graph with general expression:
>
> $$R = \frac{k}{t + a} + \ell$$
>
> where -a is the vertical asymptote, k is a scaling constant and ℓ is the horizontal asymptote.

3.4.4 The exponential decay model

As with the previous model, the a priori assumption has to be made that problem severity decreases with time. In general, an exponential decay occurs when some quantity is reducing, and the instantaneous rate of decay is directly proportional to the quantity remaining (see Appendix 3.2 and Table 15). With the same values substituted for R and t, the following hypothesis is implied:

$H_{4(d)}$	The plot of the perceived severity of a system problem, (R), versus time (t) gives an exponential function graph with general expression: $R = a\, e^{-kt} + \ell$ where a is the initial value, k is the constant of proportionality and ℓ is the horizontal asymptote.

3.5 Summary of Chapter 3

The hypotheses identified for testing in this study were formulated in this chapter, based on the research questions as proposed by Chapter 2. To test these hypotheses, two basic measures were required; one of cognitive problem-solving style, and the other of information system user satisfaction. This study adopted Kirton's KAI as a measure of cognitive style in the light of the justification given in Chapter 2 (see Sections 2.2.4 and 2.2.4.1). For an instrument to measure user satisfaction, one based on Mullany's (1989) method for measuring and quantifying user complaints was developed (see Appendix 1.2 for the complete instrument). The devised instrument records users' complaints, and assumes that generally, the fewer and less intense the complaints, the more satisfied is the user. For a summary of the research questions and the hypotheses formulated from them, see Tables 16(a) to 16(d) below.

Table 16(a): Research Question 1 and attendant hypotheses
<u>Research Question 1</u>: ***How, in general, does a user's satisfaction with a system change over time?*** (see Chapter 2, Section 2.5). **<u>Hypothesis</u>:** **$H_{1(a)}$:** During the life of the US, user satisfaction will generally rise with time as the user gains experience with the system.

Table 16(b): Research Question 2 and attendant hypotheses
<u>Research Question 2</u>: ***Does the cognitive differential between analysts and users yield advance predictions of overall user satisfaction with a given system?*** (see Chapter 2, Section 2.5) **<u>Hypotheses</u>:** $\mathbf{H_{2(a)}}$ There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***minimum*** S-Score exhibited by the user during the US's life. $\mathbf{H_{2(b)}}$ There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***maximum*** S-Score exhibited by the user during the US's life. $\mathbf{H_{2(c)}}$ There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***median*** S-Score exhibited by the user during the US's life. $\mathbf{H_{2(d)}}$ There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***mean*** S-Score exhibited by the user during the US's life.

Table 16(c): Research Question 3 and attendant hypotheses
<u>Research Question 3</u>: ***What new rules for system development would descend from cognitive style and it's measurement? For example, do new rules emerge for IS team choice based on the cognitive styles of individual users and analysts?*** (see Section 2.5) **<u>Hypotheses</u>:** $\mathbf{H_{3(a)}}$ The absolute cognitive gap, taken as | Analyst's KAI – User's KAI | is negatively associated with the S-Score during the US's life. $\mathbf{H_{3(b)}}$ The cognitive gap measured as the Analyst's KAI less the User's KAI is negatively associated with the S-Score during the US's life. $\mathbf{H_{3(c)}}$ The user cognitive style measured as the User's KAI is positively associated with the S-Score during the US's life. $\mathbf{H_{3(d)}}$ The analyst cognitive style measured as the Analyst's KAI is associated with the S-Score during the US's life.

Table 16(d): Research Question 4 and attendant hypotheses

<u>Research Question 4</u>:
How does the perceived severity of system problems change with time?
(see Section 2.5).

<u>Hypotheses</u>:

$H_{4(a)}$: The plot of the perceived severity of a system problem, (R), versus time (t) gives a rectilinear graph with expression:
$R = R_0 + m\,t$ where R_0 is the vertical intercept and m is the rate at which perceived problem severity decreases.

$H_{4(b)}$: The plot of the perceived severity of a system problem, (R), versus time (t) gives a quadratic function graph with general expression:
$R = a\,(t - p)^2 + q$ where a is the quadratic coefficient (> 0), p is the axis of symmetry and q is the minimum value.

$H_{4(c)}$: Perceived problem severity tends to decrease with time and the plot of the perceived severity of a system problem, (R), versus time (t) gives a reciprocal function graph with general expression:

$$R = \frac{k}{t + a} + \ell$$

where -a is the vertical asymptote, k is a scaling constant and ℓ is the horizontal asymptote.

$H_{4(d)}$ Perceived problem severity tends to decrease with time and the plot of the perceived severity of a system problem, (R), versus time (t) gives an exponential decay function graph with general expression:
$R = a\,e^{-kt} + \ell$ where a is the initial value, k is the constant of proportionality and ℓ is the horizontal asymptote.

Chapter 4

The research methodology and design

4.1 Introduction

This study involved two phases in respect of the data; data collection, covered in Section 4.3; and data analysis, as given in Section 4.4. In Section 4.2, the research population and sample are discussed as being made up of user-system (US) entities. The properties of USs as defined by this study are then listed. Section 4.3 explains that data collection was by way of two research instruments: the Kirton Adaption-Innovation Inventory (KAI) to measure analyst and user cognitive styles (see Appendix 1.1 and Chapter 3, Section 3.3.2), and the System Satisfaction Schedule (SSS) (see Appendix 1.2) to measure user satisfaction (S) over time. The choice of the KAI instrument to determine cognitive style is discussed further in Section 4.3.1. The development of the SSS instrument is presented in a number of stages. First, the option of using Mullany's (1989) resistance score (R-Score) is explored in Section 4.3.2. As there described, it's validity in this role was tested against the User Information Satisfaction Short Form (UIS) of Baroudi, Olson and Ives (1988) (see Appendix 2.2). The R-Score's validity was also tested against a single seven-point satisfaction scale. After this pilot study (sample: 64 user-systems (USs)), it was concluded that the UIS is a reasonably valid direct measure of user satisfaction. However, the R-Score was found to be a more valid *inverse* measure of user satisfaction. The statistical merits of the R-Score are then investigated (see Section 4.3.4). It is further reported that the R-Score's construct validity could be improved by adding a reversed, single-score measure of *overall satisfaction* to produce a *modified* version of the R-Score.

Section 4.3.5 describes and reports the results of an empirical pilot study, which suggests that the R-Score and Modified R-Score methods are not sensitive to the cognitive style of the data collector: this even though these methods are interviewing techniques. In Section 4.3.6 the Satisfaction Score (S) is developed by subtracting the Modified R-Score from a constant of 40. This was further pilot-tested (see Section 4.3.7) to show that the validity of the SSS, despite the lack of positive content, could be verified empirically. In Section 4.3.8, details of the construction of the physical SSS instrument are discussed. Particulars of the data collection procedure are given in Section 4.3.9, together with precautions taken.

In Section 4.4 the analysis of the data is described. The steps were as follows:

1) Editing of the data to remove any USs which, for whatever reason, did not exhibit all the properties given in Section 4.2 below.
2) Production of a scatter gram of S on time to seek overall trends.
3) Producing a day-wise set of S-Score readings using linear interpolation.
4) Production of a graph of the mean S on time in days.
5) Calculation of the associations (as Kendall-t_a values) between the cognitive differential and the minimum, median, mean and maximum S-Scores read for each US. No graphical techniques were envisaged for this.
6) Calculation of associations between the cognitive differential and user satisfaction on a daily bases, hence the production of a curve for comparison with the mean S curve.
7) Calculation of associations between the cognitive styles of the user and user satisfaction on a daily basis, hence the production of a curve for comparison with the mean S curve.
8) Calculation of associations between the cognitive styles of the analyst and user satisfaction on a daily basis, hence the production of a curve for comparison with the mean S curve.
9) Determination as to which of four common mathematical models best describes the change in perceived problem severity (user complaint) over time.

It should be noted that the intended methodology was always in part a discovery, especially of the exact shape and nature of the mean US S-curve, and that this study was expected to revisit the hypotheses and make adjustments to the research procedure as the analysis proceeded. Finally, the Chapter is summarised in Section 4.5.

4.2 User-Systems (USs): the research population and sample

Before considering inferences regarding the population based on the research sample, it is obviously necessary to define the data elements which comprise both. As mentioned in Chapter 3, Section 3.1, this study is an enquiry into user satisfaction and any associated features of cognitive style. As noted during the data collection for the pilot studies discussed below (see Sections 4.3.3, 4.3.4 and 4.3.5), data for one user could be collected for more than one system (s)he uses, while one system could have several users. This led to the many-to-many relationship between users and systems and the definition of the user-system (US) given in Chapter 3, Section 3.2. The present study essayed to collected data from a *sample* of USs so as to make inferences about the *population* of USs. The present study expanded upon its notion of a US, ascribing the following properties to these entities:

1) A US is a combination of a single user and a single information system which (s)he uses.
2) A US is associated with a *unique* systems analyst who may periodically interact with the user during development and maintenance of the system. If the analyst ceases interacting with either the system or the user or both, the US is considered to have terminated. (For a definition of *systems analyst*, see Chapter 2, Section 2.1. For the relationship between system usage and development, see Chapter 1, Section 1.1.1.)
3) A US exhibits a finite life which terminates when the user, for what ever reason, ceases to use the system, or when the analyst changes or is replaced.
4) A US is associated with the user's level of satisfaction (or dissatisfaction) with the given system. Understanding how this varies over the US's life time was one of the objectives of this study.
5) A US is associated with all the human characteristics of the user. In particular, this study focused on the user's *cognitive style*.
6) A US is also associated with the human characteristics of the systems analyst. As with the user, this study focused on the analyst's cognitive style and the cognitive differential between analyst and user.

The above properties were axioms assumed by this study. Obvious though most may be, they had implications for the experimental procedure and some of the precautions required. For example, how constructs such as user satisfaction and cognitive style should be measured. These are discussed further in Section 4.3.9. As discussed in Chapter 2 (see Section 2.2.4), the Kirton Adaption-Innovation Inventory (KAI) was identified as a viable option, and was used (see Section 4.3.1). For user satisfaction, the System Satisfaction Schedule (SSS) was developed. For details of this, see Section 4.3.6.

4.3 Data collection

4.3.1 The choice of the KAI instrument to measure cognitive style

As discussed in Chapters 2 and 3 (see Sections 2.2.4, 2.2.4.1 and 3.3.2), Kirton's (1976) KAI instrument was found to be a suitable candidate as a measure of cognitive style. Further justification for choosing the KAI to measure cognitive style in the present study is given in Table 17. As noted in Chapter 2, Section 2.2.4, the KAI consists of a single response sheet with 33 personality traits (see Appendix 1.1 for it's format) against which the respondent is requested to rate their ability at presenting themselves. KAI scores can range from 32 to 160 with a mean of 96 and a standard deviation of about 16. A person scoring above 96 is considered to be an innovator, and conversely, a person scoring below the mean is rated as an adaptor. However, in the range of 80 to 112 (that is, within about one standard deviation of the mean), the third cognitive style can be identified; that of the mid-scorer.

Table 17: Justification for picking the KAI as a measure of cognitive style

Feature	Description	Scholarly backing
The KAI exhibits construct validity for the construct of ***cognitive style***.	Over recent, independent empirical studies, the KAI exhibits construct validity for the construct of cognitive style.	Isaksen, et al., 2003; Korth, 2000; Bobic et al., 1999.
The KAI exhibits internal reliability.	In general, the internal reliability of the KAI, measured as a Chronbach α, is .84 or more.	Tullet & Kirton, 1995; Kubes, 1992; Goldsmith, 1985; Prato Previde, 1984; Kirton, 1976.
The KAI exhibits test-re-test reliability.	In general, the test-retest reliability of the KAI, exhibits a test-retest co-efficient of .82 or more.	Clapp, 1993; Murdock et al., 1993; Prato Previde, 1993; Gryskiewicz et al., 1986; Martin, 1978; Pottas, Unpublished.
The KAI has proven viability in IS research.	It is viable to use the KAI in IS research.	Buffinton, et al., 2002; Mullany, 1989.
The KAI is uncontaminated by level or ability.	The KAI is simple and robust, and is free from a cognitive level contaminant	see Chapter 2, Section 2.2.4.1 & Table 6.
The KAI and attendant A-I theory has a high citation rate in recent literature.	The KAI and the attendant A-I theory is much cited. The theory upon which it is based has had a considerable impact.	Desmedt, et al., 2004.
The KAI is much used in recent empirical studies.	The KAI is still much used by scholars at the present time. The KAI is in profuse use, as reported by the KAI Centre.	Desmedt, et al., 2004; Hipple, 2003.
The KAI exhibits insensitive to ethnicity.	The KAI is insensitive to ethnic or cultural differences, provided the respondent is functional in English.	Kirton, 1999.

The conditions for administration have been stipulated by Kirton (1999). These are:

- The KAI is not a self-score measure. The KAI must be taken from the respondent and scored by an authorised user.
- Feedback is to be given after administration of the KAI, based on the authorised feedback booklet (see Appendix 2.1 for the main content). This sets forth the general characteristics of adaptors and innovators. The respondent's KAI score is entered on this by the administrator, and a verbal explanation as to what this may mean, is given.

- Other conditions for administration are standard for most psychological tests, and include: comfortable, spaced seating; no time pressure; and no interruptions.
- Respondents may be cautioned that if their responses to items are bunched either to the left or right, or down the middle of the inventory, the results cannot be meaningfully interpreted.
- Of the 33 items, all but the first are scored, the latter being a blind.

(Kirton, 1999)

4.3.2 The development of an instrument to measure user satisfaction

The SSS form may be found in Appendix 1.2. As mentioned in Chapter 3 (see Section 3.3.1.4) and discussed in Section 4.3.8 below, the SSS was designed and pilot-tested for this study.

As Herzberg et al. (1959) established a link between low hygiene and complaints (see Appendix 2.7), the construct, *user satisfaction,* was argued to apply to *an absence of dissatisfaction only*, especially if the user is well aware of how that tool should function, or has expectations based on experience of how it should function (see Chapter 3, Section 3.3.1.3). As this study based its instrument on Mullany's (1989) R-Score method, the precautionary measure was taken of verifying its reliability and construct validity. For details of the R-Score method, see Chapter 2, Section 2.3.3.1 and Appendix 2.4. The associated research questions were as follows:

1) Which out of motivators and hygiene factors (see Appendix 2.7), do existing user satisfaction instruments actually measure?
2) The R-Score rates expressions of dissatisfaction. Would a satisfaction score need to rate expressions of satisfaction, expressions of dissatisfaction, or both?
3) Would a satisfaction score produced as in 2 above exhibit favorable measuring characteristics, such as a normal distribution and strong construct validity?

   and

4) Kirton (1989) suggested in his critique of Mullany's (1989) study that the personality traits of the interviewer and his/her relationship to the respondent might impact the results. Is this criticism justified?

A discussion of the tests carried out to verify the first of these may be found in Chapter 3, Section 3.3.1.2 and Table 13. The second, third and fourth tests are pilot studies of the R-Score instrument. They are described next, together with the development of the R-Score instrument into the *System Satisfaction Schedule* or SSS.

4.3.3 R-Score pilot study: empirical investigation into the validity of using the R-Score as a reverse measure user satisfaction

Pilot study research question: ***The R-Score measures expressions of dissatisfaction. Would the R-Score be a valid, inverse measure of user satisfaction?***

First, the R-Score's validity was checked against the UIS. The pilot study was conducted with a sample of 64 users over 18 organisations in the Cape Town and Johannesburg areas of South Africa. The organizations were all national, multi-national or public sector concerns whose top management was prepared to participate. These were spread over the insurance, banking, oil refinery, chain store and public utilities. 14 were private sector and 4 public sector organisations. Each produced lists of users willing and analysts prepared to take part. In every case, the user was asked to identify a system which they used extensively, and then to rate it as per the R-Score method. They were also asked to rate their satisfaction with the system on a 7-point scale with 1 representing *extremely dissatisfied* to 7 denoting *extremely satisfied*. Additionally they all completed the UIS. Two data collectors with differing cognitive styles (KAI scores) collected the data for this pilot study. For the meaning of significance levels, see Appendix 4.1, Section 4.1.2. For the meanings of the p-values given as significance levels, see Tables 38 and 39 of Appendix 4.1.

First, the relationship between the satisfaction scale, which was used as a construct validity standard (CVS), and the R-Score was tested. Using the Pearson Statistical Function as provided by the Microsoft® Excel® spreadsheet package, the Pearson linear correlation coefficient (r) was determined as -0.54425. This was found to be significant at $p = 0.01$. For details of the test, see Appendix 4.1, Section 4.1.7. The corresponding test of the CVS on the UIS yielded a Pearson correlation coefficient of

0.25574, significant at $p = 0.02$. This suggests that the UIS has a lesser construct validity on this simple test than the R-Score.

Parallel results were conducted using the Kendall t_a as the measure (see Appendix 4.1, Section 4.1.8) since this, unlike the correlation coefficient, can detect non-linear relationships. The result for the CVS on R-Score was $t_a = -0.3547$, significant at $p = 0.01$. For the CVS on the UIS, t_a was 0.3125, also significant at $p = 0.01$. However, once again, the R-Score proved to have the stronger relationship with the CVS. For the computer program used to determine the Kendall t-values and their significance, see Appendix 4.3 (first optional set of program lines). For the program's verification, see Appendix 4.4.

4.3.3.1 The construction of the Modified R-Score

An examination of the data gathered by the two researchers revealed that 10 out of the pooled sample of 64 R-Score instruments had three or fewer complaints entered. In fact three questionnaires had no associated complaints, and two, only one complaint each. In such cases, the R-Score could hardly be called a composite measure: a requirement suggested by Wanous and Lawler (1972) and adopted by most factor-based instrument designers ever since (see Chapter 2, Section 2.3). To increase the number of items on the R-Score instrument, it was proposed to reverse the CVS and to add it on, thus giving a *Modified R-Score*. As the CVS is rated using a 7-point scale (1 to 7), the reading needs to be subtracted from 8 to achieve reversal. The formula for the Modified R-Score thus becomes:

Modified R-Score = R-Score + 8 – CVS

Since a CVS had already been collected in respect of each R-Score, it was possible to determine a set of Modified R-Score readings. The correlations and associations between these and the CVS and UIS were then calculated. The correlation coefficients determined for the CVS on the Modified R-Score and the UIS on the Modified R-Score were -0.67994 and -0.29815 respectively. Their corresponding significances were 0.01 and 0.02. The associations as Kendall-t_a values were found to be -0.4449 and -0.2555, both significant at 0.01. Both the modified R-Score statistics are higher in value than the results obtained for the R-Score alone. It was consequently concluded that the Modified R-Score exhibits a higher construct validity than the R-Score on its own. For an overall comparison of the statistics discussed in this section, see Table 18(a) and (b).

Table 18: Results of pilot studies on the UIS, R-Score and Modified R-Score

18(a) Pearson Correlations:	***r***	**t_{62}:**	**Significance:**
CVS on R-Score:	-0.54425	-5.1082	Significant at p = 0.01
CVS on UIS:	0.25574	2.0830	Significant at p = 0.05
CVS on Modified R-Score:	-0.67994	-7.3013	Significant at p = 0.01
UIS on Modified R-Score:	-0.29815	-2.4595	Significant at p = 0.02
	0.05 significance level tests, with an effect size of $\rho = 0.55$ exhibit powers in excess of 99% (determined from 'Master Table', Kraemer and Thiemann, 1987. See Appendix 4.1, Section 4.1.7.2).		
18(b) Kendall Associations:	**t_a**	**$z(t_a)$:**	
CVS on R-Score:	-0.3547	-4.3056	Significant at p = 0.01
CVS on UIS:	0.3125	3.7900	Significant at p = 0.01
CVS on Modified R-Score:	-0.4449	-5.4761	Significant at p = 0.01
UIS on Modified R-Score:	-0.2555	-2.9892	Significant at p = 0.01
	0.05 significance level tests, with an effect size of $\tau_a = 0.5$ exhibit power in excess of 99% (determined from 'Master Table', Kraemer and Thiemann, 1987. See Appendix 4.1, Section 4.1.8.2).		

18(c) Goodness of Fit to a Normal Distribution:	**χ^2 (8-cells, 5 deg. freedom)**	
R-Score:	6.00	not significant at p = 0.10, **hence normality suggested***
Modified R-Score:	6.75	not significant at p = 0.10, **hence normality suggested***
UIS:	4.00	not significant at p = 0.10, **hence normality suggested***
***Power of the Goodness of Fit Test:**	**Power P ≥ 97½ %**	

Acceptance of the null hypothesis was required to show normality, hence power (P) was set so that the bias against the ***rejection*** of the null hypothesis was not unduly high. This was achieved in two ways:

1) by testing at the ***least significant*** of the standard significance levels used in this study, of 0.10 (see Appendix 4.1, Section 4.1.3); and
2) by selecting a power in relation to 0.10 such that the mistaken acceptance of the null hypothesis was ***four times less likely*** than mistaken rejection.

Using the formula $H = \beta/\alpha$ (see Appendix 4.1, Section 4.1.2.2) and substituting H = ¼ , P= **0.975**
With reference to Cohen's (1988) Table 7.3.33 (p. 244) and interpolating for the sample size of 64, the power of 97.5% is more than achieved by an ***effect size index*** (w) of 0.6. Estimates of the population effect size were made from all three samples as follows (see Appendix 4.1, Section 4.1.3.1 for the formula):

R-Score:	w ≈ 0.87†
UIS:	w ≈ 0.71†
Modified R-Score:	w ≈ 0.92†

† As these estimates all exceed 0.6, the choice of the latter value for w in the absence of any other information, was vindicated.

4.3.4 R-Score pilot study: empirical investigation into the statistical properties of the R-Score

<u>Pilot study research question</u>: *Would a satisfaction score produced as described in Section 4.3.1 exhibit favorable measuring characteristics, such as a normal distribution and strong construct validity?*

Population normality is an issue when using certain statistical tests. Confidence intervals for population means based on Student's t distributions, for instance, require the assumption of a normal population (Clark and Randall, 2004). Consequently, the R-Score, Modified R-Score and UIS data were checked for normality, using χ^2 goodness of fit tests, with eight equiprobable cells and hence 5 degrees of freedom (for details of the test, see Appendix 4.1, Section 4.1.3). The results are given in Table 18(c). All three measures tested strongly normal in terms of their weak significance levels of 0.10 and high powers (see Appendix 4.1, Section 4.1.3).

4.3.5 R-Score pilot study: Empirical investigation into the sensitivity of the R-Score to the cognitive style of the interviewer/data gatherer

<u>Pilot study research question</u>: *Kirton (1989) suggested in his critique of Mullany's (1989) study that the personality traits of the interviewer and his/her relationship to the respondent might impact the results. Is this criticism justified?*

This pilot study investigated the issue by employing two data collectors, denoted A and B respectively. Their corresponding cognitive styles, as measured by the KAI, were 107 and 91. These differ by approximately one KAI-Score standard deviation (see Section 4.3.1 above) hence appropriate two-sample tests applied to the data sub-samples collected separately were expected to reveal any sensitivity to the interviewers' cognitive style difference. The sub-sample sizes were 31 and 33 respectively. As a cross-check for procedural consistency, the same test was applied to the UIS score sub-samples.

The t-test for equality of means was conducted on the pairs of sub-samples (see Appendix 4.1, Section 4.1.11 for details of the test). As can be seen from Table 19, neither the R-Score nor the Modified R-Score were found to be from significantly differently located populations at the very weak significance level of $p = 0.20$ (two-tail tests) (see Appendix 4.1, Section 4.1.2 for a discussion of significances). However, the UIS proved to be weakly associated with the cognitive styles of the data collectors at p = 0.20. As the powers of all the tests were found to be 86%, Cohen's relative seriousness (H) was:

$$(1 - 0.86) / .20 = 0.14/0.20 = 0.7 \text{ (see Appendix 4.1, Section 4.1.2.2).}$$

In other words, the mistaken rejection of the null hypothesis is taken only to be 0.7 times as serious as mistaken acceptance. This biased the tests against acceptance of the null hypothesis. It should be noted that the tests were further biased against the null hypothesis by picking an unusually high (and hence weak) significance level of 0.20. These results lead to the conclusion that neither the R-Score nor the Modified R-Score are sensitive to the cognitive styles of the interviewers in terms of location. In other words, a satisfaction instrument based (preferentially) on the Modified R-Score would be expected to be robust to the cognitive styles of the data gatherers. This was a significant finding, since large samples of resistance or satisfaction data could only in practice be collected by more than one interviewer.

Table 19: t-Tests for difference of means for three samples of data collected by two researchers

Sample size	Researcher A 33		Researcher B 31		Power of tests: 86%* Tests all two-tail †	
Statistic	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Test-t**	**Significance**
R-Score	12.27	9.10	11.40	7.02	0.4293	**not** at p >> 0.20
UIS	9.18	12.15	12.63	7.45	-1.3772	at p = 0.20
Modified R	15.27	10.68	14.18	7.65	0.4738	**not** at p >> 0.20

*** Power of all tests**: **86%**
at significance level 0.20, effect size index d = 0.6 and pooled sample size n = 32. This ensured that in each case it was 0.7 times as likely mistakenly to reject the null hypothesis than mistakenly to accept it. Results read from Table 2.3.3, p. 32, Cohen (1988).

† For details of the tests and the determination of power, see Appendix 4.1, Section 4.1.12 .

4.3.6 The development of the Satisfaction Score (S)

By subtracting the Modified R-Score from a constant, one can define a *system satisfaction score*, thus obtaining a measure of satisfaction which is positive and more natural to the expectations of the lay person. The Modified R-Score is made up mainly of hygiene factors and ignores motivators. However, as discussed in Chapter 3, Section 3.3.1.2, so do most other scholarly instruments which claim to measure user satisfaction. It is thus argued that a reversed Modified R-Score would not be inferior to any of these on such grounds. On the contrary, it has a credible construct validity, since it runs less risk of including items not relevant to the respondent or omitting items which are (see Chapter 2, Section 2.3.1.1).

Next, consideration was given to converting the Modified R-Score into a satisfaction score. An obvious way of doing this was to subtract the Modified R-Score from a constant, which then becomes an arbitrary upper bound. As the highest Modified R-Score collected in the pilot study was 35 and to allow for possibly larger Modified R-Score values, a constant of 40 was selected.

The measure of user satisfaction, S (S-Score) was derived as follows:

$$S = 40 - \text{Modified R-Score}$$

$$\Rightarrow S = 40 - (\text{R-Score} + 8 - CVS)$$

$$\Rightarrow \underline{S = 32 + CVS - \text{R-Score}}$$

4.3.7 The Satisfaction Score (S): justifying the lack of positive content

An obvious criticism of the SSS at this stage is its lack of positive content. In the light of the link between user complaints and Herzberg's (1968) hygiene factors, and the evidence that other popular user satisfaction instruments enumerate hygiene factors only (see Chapter 3, Section 3.3.1.2 and Table 13), this criticism appeared unjustified. However, steps were taken to confirm the intended procedure empirically. The objective was to measure R-Scores against similar positive feelings about a system. This study predicted that the correlation and association between the two would exist, but be low, owed to the fact that positive expressions would be a mix of motivators and hygiene factors. On the other hand, negative expressions would denote deficits of hygiene factors only.

A sample of 20 users was identified who were willing to participate, over three companies. The users were asked to identify a system which they used extensively, and then to rate it as per the R-Score instrument. They were further asked to rate their satisfaction with the system overall to give values for the CVS, and hence values for S. Additionally they were all asked to give opinions as to what they considered *good* about the system. The importance of each of these opinions was rated similarly to their R-Score complaints. The instrument for measuring the combined positive and negative factors is given in Appendix 4.2. As the R-Score and CVS are integral parts of the S-Score, the opportunity to recheck the statistics for these against the last pilot study (see Section 4.3.3.1 above) was taken. The results are given in Table 20. For the computer program used to determine the Kendall-t_a values and their significance, see Appendix 4.3 (second optional set of program lines). For its verification, see Appendix 4.4.

Table 20: Results of a pilot study on the R-Score, S-Score and Positive Ratings

Pearson Correlations: †	***r***	**t_{18}:**	**Significance:**	***r*, previous values**
CVS on R-Score:	-0.2421	-1.9646	p = 0.10	-0.54425
CVS on S-Score:	0.4690	4.1812	p = 0.01	-0.44490*
Positive Ratings on R-Score:	-0.2623	-2.1399	p = 0.05	-
Kendall Associations: †	**t_a**	**$z(t_a)$:**		**t_a, previous values**
CVS on R-Score:	-0.1579	-1.0380	**not** at p = 0.10	-0.35470
CVS on S-Score:	0.3368	2.1901	p =0.03	-0.44490*
Positive Ratings on R-Score:	-0.1895	-1.1918	**not** at p = 0.10	-
Goodness of Fit to a Normal Distribution: †	**χ^2 (5-cells, 2 degrees of freedom)**			**χ^2, previous values**
R-Score:	4. 00		**not** at p = 0.10	6.00
S-Score:	2. 00		**not** at p = 0.10	6.75*

† **Power of the Tests**:
Correlations: 0.05 significance level, effect size ρ = 0.55, power exceeds 80%.
Associations: 0.05 significance level, effect size $\tau_a = 0.5$, power exceeds 60%.
(determined from 'Master Table', Kraemer and Thiemann, 1987. See Appendix 4.1, Sections 4.1.7.2 and 4.1.8.2).

Goodness-of-fit tests:
From w = 0.60 (from Table 18, see note †), n = 5, ν = 2, p = 0.05,
the **power** was estimated to be about **80%**. See Table 7.3.30, p. 242, Cohen (1988).
See Table 18 (above) and Appendix 4.1, Section 4.1.3, for details of the methods.

* Previously tested as the 'Modified R-Score' (see Table 18).

It will be noted from Table 20 that the rectilinear correlation between the positive ratings and the R-Score is significant but small. The association between the two, however, is not significant at $p = 0.10$. Although the power of the tests on t_a at the 0.05 significance level is not high, the actual value obtained for t_a is not high either, even if it were more significant than the test suggests (see Appendix 4.1, Section 4.1.8 and Tables 39 and 40). Together these results confirm the prediction of this study, that the positive ratings are not strongly correlated or associated with deficits in the user-specified hygiene factors. They further vindicate the claim that the positive factors are a mix of motivators and hygiene factors, and that a more reliable measure of satisfaction is obtained if positive ratings (other than the CVS) are largely omitted from the proposed instrument.

The remaining statistics given in Table 20 generally confirm the findings of the previous pilot study. The S-Score (which only differs from the Modified R-Score by its difference from a constant) is found to test normal, not only at the weak significance level of 0.10 but also at a power exceeding 80%. The S-Score also exhibits a higher correlation and association with the CVS, suggesting its superior construct validity.

4.3.8 The development of the physical System Satisfaction Schedule (SSS) instrument

Of the various instruments discussed in Chapter 2 to measure user satisfaction, none were found which could guarantee reliable results after repeated use with the same respondent. All such instruments, except the SSS, are clearly intended for once-off use. Mullany (1989) had success in the use of the R-Score to measure user dissatisfaction, and hence its surrogate, user resistance. The strength of this instrument lay in the fact that the problems specified were entirely *user specified*, and yet it contrived to give a quantitative result for the user's complaining behaviour. This led to the speculation that a user could rate the same self-generated complaints repeatedly over time, specify when any particular complaint ceased to be of effect, report any new complaints which had arisen, and so yield a usable set of weighted complaints as a score, continuously over the

US's life. This suggested that the R-Score measure could be modified into a user satisfaction instrument as follows:

- Include a CVS scale;
- Give spaces for the repeated ratings of the CVS and user complaints, together with the date sequence; and
- Give detailed instructions so that the data collection performed by way of this instrument could be standardised.

The instrument thus developed, the SSS, is given in Appendix 1.2. The four A4 pages are printed back-to-back on one A3 sheet, thus enabling the whole instrument to be folded into one A4-sized document.

4.3.9 The research procedure

The essentials of this study were based on a sample initially of 87 USs, 67 distributed over 9 South African organisations (collected prior to 2000), and 20 from 3 New Zealand organisations (data collected 2004-2005). Each organisation identified *key users* for a given system. Every one of these was interviewed on a face-to-face basis as the first step. At this interview, the SSS form for the system was duly completed with as much of the demographic and other data as the user was prepared to allow. In fact, no users objected to any of the information requested, so in all cases the front page of the SSS form (see Appendix 1.2) was completed in full. The user was then invited to complete the KAI instrument under the conditions specified by Kirton (see Section 4.3.1 above).

As discussed in Chapter 2, Section 2.2.4.1, the appearance of the KAI instrument might be considered second-rate by some present-day respondents. As this could jeopardize the seriousness with which they might complete the form, the research design ensured that each respondent completed the KAI with the interviewer's individual supervision (see Chapter 2, Section 2.2.4.1). Any belief that the KAI was a second-rate instrument (see Chapter 2, Section 2.2.4.1) was countered by a brief, verbal description of the background to the instrument, its eminence and its current popularity among researchers. This description excluded any Adaption-Innovation Theory, however. That was only disclosed to the respondent after the author had scored the KAI as directed by Kirton (1999). The blind (Item 1) was completed first as a trial item in conjunction with the author (see Appendix 1.1). Once the respondent had completed the remaining 32 items, the interviewer checked through the completed instrument prior to scoring it, and where necessary queried any suspect entries with the user. The respondent was given the opportunity to discuss his/her KAI score and its meaning. A copy of the official KAI feedback form, duly completed, was then handed to the respondent. The user was asked to identify the key analyst or systems analyst of the system in question. The user's opinions of the system were then recorded on Page 2 and in Column 1 of Page 3 of the SSS form (see Appendix 1.2), and weighted according to the scale at the bottom of page 2 of this instrument.

Precautions taken at the initial user interviews, in addition to those mentioned above for the administration of the KAI, were as follows:

1) It was stressed that all the user's responses would be kept confidential, and that agreement had been reached that the organisation was not privy to any of it. This agreement had been negotiated with each of the chief executives in advance.

2) An outline of the research was explained in simple terms to the user. Questions were invited and concerns addressed.

3) It was explained to the user that (s)he would be involved in short, follow-up phone calls at approximately three-month intervals.

4) The SSS form was shown to the user throughout the data-gathering process. The approach was taken that the investigator and the user were to complete the SSS together.

5) The user was reassured that, although the analyst was to be interviewed, none of the contents of the SSS form would be made available to him/her.

6) The date of the interview was entered in the appropriate column, and the overall satisfaction was rated first. Initially the user was asked:

   "*In general, are you satisfied or dissatisfied with the system?"*

   If the user specified that (s)he was generally **satisfied**, they were asked to refine their choice thus:

   "*Would you say that you are **slightly**, **quite** or **extremely** satisfied with the system?"* The response of 5, 6 or 7 was then duly recorded (see Appendix 1.2).

7) A similar process to obtain ratings of 3, 2 or 1 was obtained if the user claimed to be generally **dissatisfied** with the system.

8) If the user declined to specify general satisfaction/dissatisfaction, a rating of 5, 4 or 3 was obtained by asking:

   "*Would you say that you are **slightly satisfied*** with the system, ***slightly dissatisfied*** with it, or ***definitely neutral***?" giving scores of 5, 3 or 4 respectively.

9) Next, the user was asked to dictate problems with the system as follows:

   "Please enumerate all the problems which you or others find with the system. I am going to record these briefly, so I may need to ask you to pause from time to time."

   Where possible, a summary of each problem was recorded in two lines (one grey, one white, see Appendix 1.2). Care was taken ***not*** to request complaints from the user, but only for an articulation of the problems at hand.

10) Where a user appeared to repeat a problem, the following response was given:

    "I seem to have misunderstood, because I cannot tell the difference between that problem and a previous one you mentioned, which I have down as . . . "

    and the previous problem was read back to the user. If the user insisted that there was a difference, the repetition was recorded as a separate problem.

11) Once all the problems had been recorded, each needed to be verified and rated on the Problem Severity Scale. The ratings were then recorded in the corresponding cell of Column 1 on Page 3 of the SSS form. The following was said to the user:

    "I shall now read my summaries of each problem back to you for checking. Once you are sure that I have recorded each problem correctly, I will ask you to rate their severity."

12) Each problem was read, verified and rated in severity before the next problem was read. Once the user had agreed that the problem was accurately recorded, the following was said:

    *"Would this problem best be described as **a slight problem**, **a rather serious problem** or **a very serious problem**?"*

    These correspond to severity ratings of 2, 4 and 6 respectively (see Appendix 1.2). The user was then asked to refine his/her rating. If, for example, the user selected (4) **a rather serious problem**, the following was said:

    *"Would it be best described as **a serious problem**, **a rather serious problem** or **a significant problem**?"* hence obtaining a rating of 5, 4 or 3.

13) When taking leave of the user, the data gatherer thanked him/her for their assistance. The user was then reminded that telephonic interviews would follow, and copies of the response scales (but ***not*** of the responses themselves) were left in his/her possession for use during these interviews.

14) Before leaving the premises, all the complaint summaries were scanned for legibility, so that they could be read back to the users later, possibly by another person.

15) Finally, notes were made immediately after the interview of any unexpected and unusual circumstances or occurrences.

Once the user had been interviewed, an appointment was made to interview the chief analyst as identified by the user. In two cases, this differed from the person specified by the chief executive, and required negotiation with all parties concerned. However, in the end all the analysts interviewed were those identified as the chief analysts of their systems by the users concerned. At these interviews, the KAI was administered to the analysts in the same manner and with the same precautions as it was to the users.

Follow-up interviews were made telephonically to the users at approximately three-month intervals. At each of these, the user was first asked to re-rate their overall satisfaction with the system concerned. They were then requested to review, expand and/or modify their responses of the previous interview. The modified responses were recorded in Columns 2 to 12 of Page 3 of the SSS (see Appendix 1.2). New comments were invited, and when made were rated as previously described. The general procedure and precautions taken during the telephonic interviews were as follows:

1) At the appropriate time (about 90 days since the previous interview, face-to-face or telephonic), the user was telephoned, the number having been recorded on Page 1 of the SSS (see Appendix 1.2). The user was reminded of the previous interview and system under consideration. If the user was unavailable to be interviewed at that moment, an appointment was made to phone back.

2) The user was referred to his/her copy of the rating scales. If the user had mislaid this, the offer was made to dictate them over the phone, or to send them by fax or e-mail.

3) The date was filled in at the top of the appropriate column on Page 3 of the SSS (see Appendix 1.2) (for example, Column 2 for the first telephonic interview).

4) Next, the user was asked whether or not they still used the system. The relevant header cells were then marked Y or N for ‘yes’ or ‘no’ respectively. If not, the reason or reasons were ascertained in as much detail as possible, and the discontinuance date was recorded. The user was further asked whether or not the analyst had changed or ceased to be involved. Once again the information was duly recorded.

5) The user was next reminded of their previous overall satisfaction rating (CVS), and asked to modify their response in the light of experience since.

6) Each problem, current at the previous interview, was then read back to the user. The last rating was specified, and the user was asked to re-rate the problem on the Problem Severity Scale. The result was duly recorded.

7) If the previous rating was (1) (*no real problem*), the user was asked:

   "*Is this problem worth further consideration or not?"*

   If the user specified **not**, the problem was rated as zero and was not raised again at subsequent interviews, unless by the user.

8) After all the ratings had been revised, the user was asked:

   "Are there any other problems which have become apparent since the last interview?"

   If so, the problem was recorded below the others on Page 2 of the SSS (see Appendix 1.2), and a new rating obtained as previously described.

9) The user was finally thanked for their time and remind that he/she would be contacted in about three months' time.

10) All new entries, especially for new complaint summaries, were scanned for legibility, and notes were made immediately after the interview of any unexpected and unusual circumstances or occurrences.

The results of this study are given in detail in Chapter 5, after discussion of the data.

4.4 Analysis of the data

In this section the analysis of the data is discussed. It needs to be remembered, however, that in the case of the shape of the mean US S-Score time series, little could be conjectured other than an expected secular rise as the user becomes more familiar with the system (see Chapter 3, Section 3.3.1.4). Consequently, the processes outlined here were extended in the light of the unfolding analysis.

4.4.1 Editing of the data

Most organisations were specifically asked to make available for study, systems which had either 'gone live' within 90 days or were going to do so within the next 90 days. Despite this request, the systems of 7 participating users had not been implemented within a year previously. Some USs terminated after only one reading had been taken, normally because the user had left the organization or for some other reason, no longer used the original system. As single readings contain no trend information whatsoever, all such cases were removed from the sample. In a few other cases, USs terminated after only two readings. As these represented periods of only some three months, when the investigation aimed at a period of 18 months to 2 years, these cases were also removed from the sample. All in all 25 USs out of 87 were thus removed, resulting in a remaining sample of 62 USs (45 South African and 17 New Zealand systems). At first sight, the attrition rate seems rather high. However, one should note that the 25 removed USs only contributed 27 S-readings out of 360, owing to the more frequent readings made for the remaining USs. For a frequency distribution of numbers of readings, see Table 21.

Table 21: Frequencies of readings taken for the sample of 62 User-Systems (USs)

No. Readings:	3	4	5	6	7
Frequency:	11	0	13	31	7

As with the pilot study described in Section 4.3.3, all the organizations involved produced lists of users and analysts willing to participate. The 62 US sample, classified by system type, organisation and sector, are given in Tables 22(a) to 22(c) below.

Table 22(a): Composition of the research sample of 62 User-Systems (USs) by system type

Type of system	No. of USs
Stock Control (manufacture)	9
Stock Costing (factory works)	9
Motor Fleet Control and/or Maintenance	8
Manufacturing Control	6
Customer Accounts (industrial)	5
General Accounting	5
Point of Sale	4
Purchasing (industrial)	4
Security/Surveillance (industrial)	4
Mortgage Processing (bank)	2
Student Records	2
Insurance Claims	1
Office Automation	1
Telecommunications, bank cards	1
Works leasing	1
Total:	**62**

Table 22(b): Composition of the research sample of 62 User-Systems by type of organisation

Type of organisation	No. of USs
Manufacturing / industrial	34
Transport and shipping	14
Banking	5
Insurance	5
Educational	4
Total:	**62**

Table 22(c): Composition of the research sample of 62 User-Systems by sector

Sector	No. of USs
Private	44
Public	18
Total:	**62**

The South African organisations in which data collection took place are all large national, multi-national or public sector concerns with well-developed infrastructures. They are operating in rather third-world market- and macro-environments, with the threat of ever-increasing inflation and tax (Gerber, Nel and van Dyk, 1996). However, despite the fact that all the data were collected well after the abolition of apartheid in 1990, none of the reasons for dissatisfaction expressed in the SSS was politically based, nor did any respondent specifically range their comments against prevailing market behaviour or state legislation. Precisely the same was observed in the New Zealand respondents, even though New Zealand clearly exhibits other macro- and market-environments for business. Insofar as the SSS is able to measure user satisfaction, then user satisfaction was found to be a function of the micro-environment only; that is, the internal environment of the organisation and the job context of the user.

To test for differences between the two groups of data collected under these rather different environmental conditions, the South African and New Zealand US data were tested for differences in statistical location. As reported in Chapter 5, Section 5.2.1, no difference in location could be supported, suggesting insensitivity of user satisfaction to all but the micro-environment of a business, at least in respect of this study's sample and sub-samples.

USs in the sample were ultimately positioned on a common time scale from 0 to Day 730. Day 0 was defined as the first day on which the user actually interacted with the system. Hence the analysis spanned an effective US life of some two years, although the physical data collection took substantially longer (see Section 4.3.9). The results of the analysis are given in detail in Chapter 5.

4.4.2 Initial data plot

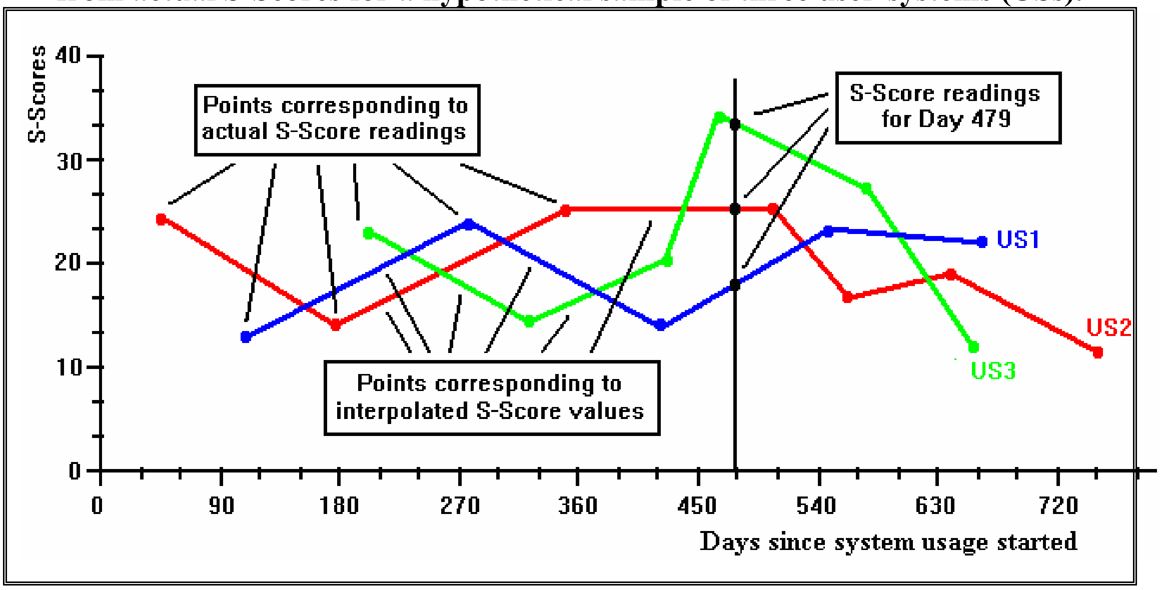
To gain familiarity with the collected data, a scatter gram of all the raw S-Scores against time was plotted. At this stage, an attempt was scheduled to fit a linear regression line, if possible, thus testing hypothesis $H_{1(a)}$:

> ***During the life of a US, user satisfaction will generally rise with time as the user gains experience with the system.***

4.4.3 The use of linear interpolation to obtain S-Score data for every day in the time domain

Although only 3 to 7 S-readings were taken for each US, all intermediate points for each were to be estimated by linear interpolation. See Appendix 5.2 for details on how such interpolated values were calculated. To understand further this process the present study provides Figure 4 below. This illustrates how a set of three interpolated values for the S-Scores from three hypothetical USs would be determined for day 479 since system usage began. The corresponding points for each system are plotted and joined, giving the associated graphs represented in the three different colours. To determine the S-Scores for Day 479, the vertical coordinate for Day 479 is drawn in as a perpendicular, and where this intersects with the three graphs, the associated S-values are read off the vertical axis.

Figure 4: Illustration of an example to determine interpolated S-Score values from actual S-Scores for a hypothetical sample of three user-systems (USs).



Although this process cannot claim to provide exact daily data for each US, its merits are argued against the alternative of physically obtaining responses from each user daily over a period ranging from months to years. It is argued that the attrition caused by the latter process, even if feasible, would attract far more serious errors than the proposed scheme of taking a mere 3 to 7 readings several weeks or months apart, and then using interpolation to estimate the rest.

4.4.4 Graph of the mean S-Score over time

Based on the daily S-Score data, either read or interpolated, the study aimed to produce a plot of the mean S over time from Day 0 to the maximum number of days for which any US was surveyed. This was expected to give information as to how, on the average, user satisfaction evolves over the life of a US. Confidence intervals as estimates for US population mean Ss were to be used to show the extent to which actual features of the sample curve predict the population curve. Further confirmation or rejection of hypothesis $H_{1(a)}$ was thus expected, together with more detail.

4.4.5 The relationship between the analyst-user cognitive differential and overall user satisfaction

Hypotheses $H_{2(a)}$ to $H_{2(d)}$ posit a negative association between the cognitive differential and, respectively, the minimum, median, mean and maximum S-Score values measured for each US. No graphical processes were envisaged for this. The calculations to obtain Kendall-t_a values were undertaken by a computer program developed specifically for this study (see Appendix 4.3, first optional set of program lines. See also Appendix 4.4 for its verification). Discussion of the results, including their strengths and significances, was expected.

4.4.6 The varying relevance of cognitive style models throughout US life

Hypotheses $H_{3(a)}$ to $H_{3(d)}$ posit a negative association between user satisfaction and the following respective cognitive models (determined as KAI scores):

- the absolute cognitive differential;
- the algebraic difference between analyst and user cognitive styles;
- the user's cognitive style; and
- the analyst's cognitive style.

These hypotheses were only intended as a guide to the relevance of each cognitive model, the deeper objective being to show *when* during a US's life, each cognitive model is *most* relevant and when least. In other words, this part of the analysis is an enquiry into at which stages of a US's life each cognitive model impacts user satisfaction, and to what degree. To fulfill this objective, another computer program was developed (see Appendix 5.5) to determine Kendall-t_a values and to plot these values against time for each of the four cognitive models. The program was also designed to show significance levels and to provide an output of values in the form of a text file, for further processing. The expectation was that the t_a versus time graph for each of the four cognitive models could then be compared with the mean S-Score plot to determine any associated behaviour.

4.4.7 Trend models for the change in perceived problem severity over time

Hypotheses $H_{4(a)}$ to $H_{4(d)}$ suggest that each of a linear, quadratic, reciprocal and exponential decay model fits the change in perceived problem severity with time. A program was developed to plot the mean individual problem severity on time (see Appendix 5.6, Section 5.6.1). Four further programs were then developed to fit each of the hypothesised models, to data gathered for individual problems. They were also designed to give the least squares statistic of fit (see Appendix 5.6, Sections 5.6.2 to 5.6.5). The model with the lowest of these would then be found to be the best fitting.

4.5 Summary of Chapter 4

The objective of the research procedure was to collect user S-Scores over time, together with the User and Analyst KAI scores for the testing of the hypotheses developed in Chapter 3 (see Tables 16(a) to 16(d) inclusive). The choice of the KAI instrument to measure cognitive style was confirmed in Section 4.3.1. The construct validity of Mullany's (1989) R-Score, as a reverse measure of user satisfaction has been explored (see Sections 4.3.2 to 4.3.6). In Section 4.3.7 the method for calculating the Satisfaction Score (S) was developed, this by subtracting the Modified R-Score from a constant of 40. The latter was further pilot-tested (see Section 4.3.7) to show that the validity of the S-Score, despite the lack of positive content, could be verified empirically. In Section 4.3.8, physical details of the SSS instrument are discussed.

Section 4.3.9 outlines the way the data were collected in this study from a sample of user-systems (USs). The methods followed have been described together with the precautions taken. The intended procedures of data analysis have been summarised in Section 4.4. First, these were to involve the determination of a mean S-Score curve. This was expected to shed light on how user satisfaction in general evolves over a US's life. Further, the Kendall-t_a was to be used to find and test relationships between the absolute cognitive differential and measures of overall user satisfaction. The associations between the four cognitive measures given in section 4.4.6 above, and the S-Score, calculated daily as Kendall-t_a values, were to be plotted against time. From this, it was hoped that any associated behaviour between the S-Score curve and each t_a curve could be studied. Finally, a curve-fitting process was envisaged, which would allow the determination of which of four fundamental mathematical models best fits the reduction of perceived system problems with time (see Section 4.4.7).

It should be noted that the intended analysis methodology was always in part a discovery, especially regarding the exact shape and nature of the mean US S-Score curve, and that revisiting of the hypotheses was expected. Although all the procedures discussed in this chapter were completed and reported on, some supplementary testing for reliability and validity, where appropriate was carried out.

Chapter 5

Results

5.1.1 Introduction

This chapter discusses the outcomes and observations of the present study and their analysis. In the first instance, Section 5.2 describes the data collected and the initial findings based on these. As noted in Section 5.2, the data for all the sample user-systems (USs) were plotted on a common time-scale of 731 days (spanning two years). Inferences are made throughout the chapter for the population of USs based on the sample analysis over this 0-730 day domain. The findings include tests of all the hypotheses identified in Chapter 3, Section 3.5 and Tables 16(a) to 16(d), using data collected as described in Chapter 4. However, results beyond these were also found. Detailed lists of the findings are given in Tables 27, 28, 30, 33 and 34.

In Section 5.2.1 the research procedure is summarized, and in Section 5.2.2, a description of the testing of hypothesis $H_{1(a)}$ is given. The test was found to support the hypothesis. Stating that:

> *During the life of a US, user satisfaction will generally rise with time as the user gains experience with the system,*

two tests were performed on this hypothesis, the first of which showed significance at $p = 0.005$, and the second at $p = 0.01$ (see Section 5.2.5). Also during this phase of the statistical analysis the distribution of terminating USs was investigated. It was found that probably fewer than 26% of USs outlast two years (see Section 5.2.2 and Figure 6). The desirability of dividing the domain up into five intervals; three of four months followed by two of six is discussed and justified. The erratic behaviour of the mean-S curve on Intervals 1 and 5 were found to be of interest. In the first interval, this is put down to user responses to new systems, while in the fifth it is ascribed to the steady termination of USs, some with more extreme mean-S values than others. The best-fitting curve to the mean-S time-series was shown to be a rectilinear graph with a positive slope. For a detailed summary of the results for Section 5.2, see Table 27.

The phase of the analysis documented as Section 5.3, tested hypotheses $H_{2(a)}$ to $H_{2(d)}$. These state that the absolute analyst-user cognitive gap is associated with:

the minimum; mean; median; and *maximum*

of the overall S-Score readings for each US.

All but hypothesis $H_{2(a)}$ tested significant at values of $p = 0.01$ or $p = 0.05$. However, the results were found to be weak, since the most significant association turned out to be only 0.2041 in magnitude, yielding a maximum discordance of just over 60%, despite its statistical significance.

As discussed in Section 5.4, this study set out to test hypotheses $H_{3(a)}$ to $H_{3(d)}$ over the entire two-year time domain so as to find where each hypothesis is supported and where each is rejected. The four KAI-based factors (cognitive models) used for each system were reflected in these hypotheses, and were:

The absolute analyst-user cognitive gap (difference in KAI scores);
The cognitive gap calculated as Analyst KAI less User KAI;
The User KAI; and
The Analyst KAI.

The results were then graphed for each hypothesis (see Figures 11 to 14). A summary of the results are given in detail in Table 30. In brief, the absolute cognitive gap was found to be highly significant during the first interval in the neighbourhood of day 85, and in the last, in the neighbourhood of day 652. Similar, though less extreme behaviour is exhibited by the signed cognitive gap (Analyst KAI- less User KAI-Score) in the neighbourhoods of the same time-points. This was used to show the asymmetric nature of the effect of the cognitive gap: that is, an innovative analyst's system was found to be less satisfactory to an adaptive user than an adaptive analyst's system to an innovative user. This was put down to a general characteristic of innovators, that they are:

> "Seen as undisciplined, thinking tangentially" (Kirton, 1976),

and are:

> "seen as abraisive, creating dissonance" (Kirton, 1976).

The users' cognitive style was not found to impact user satisfaction anywhere on the domain. However, an innovative analyst was shown to heighten user dissatisfaction in both the first and fifth intervals of the domain. This again demonstrates the asymmetric nature of the impact of the cognitive gap. For a detailed set of results for Section 5.4, see Table 30.

The final phase of the analysis is described in Section 5.5. This attempted to test which of four mathematical models best fits the problem-factor data extracted from the System Satisfaction Schedules (see Appendix 1.2) for each US. Only USs in which more than four readings had been taken, were included in this phase of the analysis. Of the original 62 USs only 40 could be selected under this criterion and this gave a second sample of 204 problem-factors for investigation. Owing to the erratic nature of the data over Interval 5 as USs generally terminated, a reduced domain from day 0 to day 540 was employed for this part of the research. The four models tested were the rectilinear, quadratic, reciprocal and exponential models. The reciprocal model was found to be the best-fitting, followed by the exponential. However, on further analysis it was found that these two models yielded curves which are very close to each other and that in practical terms, they are interchangeable. A detailed set of results for Section 5.5 is given in Table 33.

Finally, the chapter is summarized in Section 5.6. This is prefixed by Table 34, which gives a summary of key results for the whole study.

5.2 The data: an overall description and assessment

As mentioned in Section 5.1, a standard common domain of 731 days, (numbered 0-730), was established, on which the S-data from each of the sample USs were plotted and analysed. This was done so that each US shared a common start of 0 days and hence the mean behaviour of the sample could be observed at similar periods of the USs' 'lives'. The data for the individual USs were not necessarily collected concurrently, of course. This chapter refers to the 'standard time domain' or 'the domain' as a hypothetical time scale, common to the sample USs, and potentially generalisable to the population of USs.

5.2.1 Summary of research procedure and the elimination of unreliable data

As outlined in Chapter 4, Sections 4.2.9 and 4.3, the essentials of this study were based on a sample of 62 user-systems (USs) from 12 organisations distributed over South Africa and New Zealand. The sample, initially of 87 USs, was composed of 67 distributed over 9 South African organisations, and 20 from 3 New Zealand organisations. 25 of these were discarded, however, owing to one or more of the following:

- The US terminated before at least three readings could be taken;
- The analyst changed before at least three readings could be taken;
- The user disagreed with the organization as to when he/she started to interact with the system by more than 120 days; and/or
- On investigation, the user had interacted with the system for longer than 200 days, despite the organization's assurance that the system had only 'gone live' within the previous 90 days. This reduced the South African component to 45 USs and the New Zealand component to 17, yielding an overall sample of 62 USs.

As the South African data were collected chronologically before the New Zealand data, the first question to be addressed was the possible influence of this dichotomous sample on the present study. The main concern was the difference in both organizational environment (see Chapter 4, Section 4.4.1) and technology between the USs from the two different countries, and from two different time periods. However, in the first instance, this study did not find any theoretical reason why the results sought should be technology-dependent. After all, the first of its principal measures, the KAI, is a psychological test related to personality and a person's interactions with other personalities (see Chapter 2, Section 2.2.4). The other major instrument is the SSS. As discussed in Chapter 4, in Sections 4.3.5 to 4.3.8, the SSS and its parent instrument, the R-Score, avoid technology dependence by listing the respondents *own* perceptions of their USs. The present study held to the view that, so long as the situation prevailed where each US in the sample was the product of a user and a systems analyst, aspects of their personalities would be the issue at stake, not any one or other technology. However, some might conjecture that a user would be *more satisfied* with *more recent* technology than older technology, and that this might impact the overall values for S. The issue was thus investigated statistically.

The input datum from each US was taken as the mean-S over the period of data collection. If the data samples were technology-dependent, and this dependence was exhibited by the mean-S-values for all the USs in each sample, a difference in location for the mean of the mean-Ss would be expected. Bartlein's (2005) t-test for a difference between independent population means where the population variances are not assumed to be equal, was employed (see Appendix 4.1, Section 4.1.11). The procedure was biased in favour of the hypothesis that the mean difference is significant, by using the weak significance level of 0.20 (see Appendix 4.1, Section 4.1.2 for strengths of significance levels). Despite the bias, the test failed to reject the null hypothesis of zero difference. The test also exhibited a power of 0.80 for an effect size index of d = 0.7 (see Appendix 4.1, Section 4.1.11 for details).

Although this test is claimed to be robust against departures from population normality (Zar, 1999), the present study repeated the investigation using the Mann-Whitney U-test, which is said to be less distribution dependent (see Appendix 4.1, Section 4.1.9 for the details). Using the normal approximation to the U-statistic, this test also failed to reject the null hypothesis of equality of location at a significance level of 0.20. The power of this test is nearly as high as the power of the t-test given above (Kraemer and Thiemann, 1987). In short, this test did not support the conjecture that the S-values were differently located in the samples either. In consequence of this, and owing to the rather small size of the New Zealand sample (17 USs), the present study took these two samples as a single sample of 62 USs for all further analysis.

The process of data collection employed Kirton's KAI to measure each user's and each analyst's cognitive style. At an initial face-to-face interview, the user's S-Score was determined using the *System Satisfaction Schedule* (SSS) (see Appendix 1.2 for the instrument). For details of the research procedure, see Chapter 4, Sections 4.2.9 and 4.3.

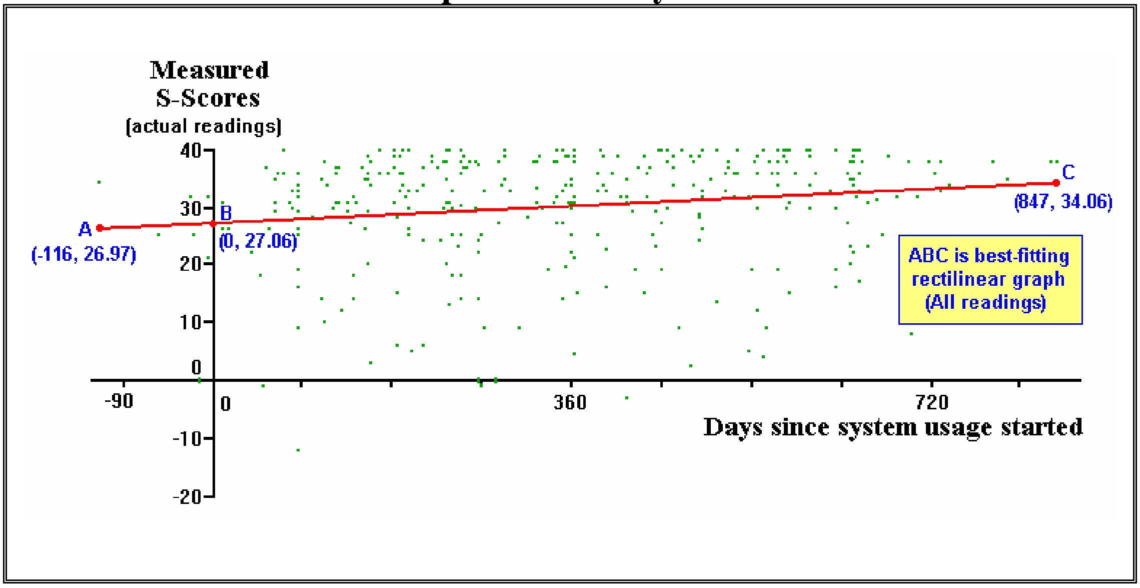
This study consequently had four key sets of initial readings for each sample US:

- the number of days since the user began (or until the user did begin) interacting with the working system,
- the user's cognitive style as a KAI-score,
- the analyst's cognitive style as a KAI-score, and
- the user's satisfaction with the system as an S-Score.

Despite the request to organizations that they make users available who had started using the associated systems within the previous 90 days, some respondents claimed that they were still due to commence system use. A total of 6 USs remaining in the sample were affected by this. In one case, the user only commenced using the system 116 days after the official start date. However, the 6 users concerned seemed quite happy to express opinions on their systems in the light of development progress up to that stage. After all, system usage and development are to an extent, inseparable (see Chapter 1, Section 1.1.1). Their responses were recorded, but no further satisfaction readings were taken until after day zero had passed. The USs were thus surveyed initially over periods ranging from -116 to 847 days (domain referenced), yielding from 3 to 7 readings each.

Altogether, 333 S-Score readings were taken, spread over the combined sample of 62 USs and over a common domain from -116 to 847 days. The plot for all of these is given in Figure 5, with the best-fitting rectilinear regression line ABC inserted. The scatter gram was created by a program developed specifically for this study, the source code of which can be found in Appendix 5.1.

Figure 5: S-Scores (actual readings) on Time (in Days). Sample: 62 user-systems.



This study is based in part on the premise developed in Chapter 3 (see Section 3.3.1.1) that satisfaction can only be reliably rated by a user who has had experience of the system. Day 0 was therefore consistently defined as the first day on which the user actually interacted with the system, although data collection for this study started earlier in 6 cases. The system inherent in each and every sample US was still under development or early maintenance on, or by day 0. S-Scores cannot exceed 40 (see Chapter 4, Section 4.3.6). However, they can drop below zero. This occurred in the case of four readings only, the lowest of which was -12. The S-Score data thus ranged from -12 to 40 over the whole time domain. Hence, as will be evident from the plots of the actual readings given in Figure 5, all but 4 of the S-Score data were above zero, and all but 6 occurred from day zero of the common time domain, onwards.

As discussed in Sections 5.3 and 5.4, the tests for the significances of associations require at least 10 USs to be active on any day of the analysis. This requirement was met for days 15 to 702 inclusive. On account of this, and to give an overall time window of two years, this study standardized on a 731-day time domain with units denoted day 0 up to and including day 730. With the elimination of data occurring before day 0 or after day 730, 320 values remained as the primary sample of S. As the minimum of 10 USs could not be met before day 15 nor after day 702, the domain was decreased accordingly for those parts of the analysis employing day-wise association statistics (hypotheses $H_{3(a)}$ to $H_{3(d)}$. See Sections 5.4 and 5.5). Additionally, standardizing on day 0 as the starting point of the domain is consistent with the premise that a user must have had at least some experience of interaction with the system before (s)he is capable of rating his/her satisfaction with the system (see Chapter 3, Section 3.3.1.1).

This study investigated the spread of the data over the standardized domain (days 0 to 730 inclusive) by using the two-sample test for a difference in variances, as outlined by Zar (1999). For the formulation of this, see Appendix 4.1, Section 4.1.12. Of significance, is the need to keep the sample sizes as near equal and as large as possible while adequately covering the time domain. In consequence, the variance and standard deviation of the data were measured twice; once in four groups of near-equal numbers of data and once in five. In the case of the former, the 320 S-data over the 0-730-day domain were divided into four groups of approximately 80, while in the second, it was divided into five groups of approximately 64. Slight variations from these figures were allowed to ensure that no data groups overlapped time-wise. As outlined in Appendix 4.1, Section 4.1.12, the tests involved taking the ratio, greater than 1, of each pair of variances as an F-statistic and comparing this to tabulated critical values. The results of these tests are given in Tables 23(a) and 23(b).

Table 23(a): Tests for differences in variance.
Sample: 62 USs. Data divided up approximately into quarters.

Powers of all tests exceed 0.95

(Effect size based on upper and lower standard deviations of 12 and 8 respectively. Power read from "Master Table", Kraemer and Thiemann, 1987.)

FIRST QUARTER OF SAMPLE		First-Second Quarters	First-Third Quarters	First-Fourth Quarters
Day Range:	0-189	H_0: $\sigma_1^2 = \sigma_2^2$	H_0: $\sigma_1^2 = \sigma_2^2$	H_0: $\sigma_1^2 = \sigma_2^2$
Quarter Sub-sample size:	79	H_1: $\sigma_1^2 \neq \sigma_2^2$	H_1: $\sigma_1^2 \neq \sigma_2^2$	H_1: $\sigma_1^2 \neq \sigma_2^2$
Quarter Mean:	28.2025	F=1.058154	F=1.172248	F=1.233596
Quarter Standard Deviation:	10.0956	$F_{0.10(2), 79, 78} = 1.46$	$F_{0.10(2), 78, 79} = 1.46$	$F_{0.10(2), 78, 80} = 1.46$
		Accept H_o of equality	Accept H_o of equality	Accept H_o of equality
SECOND QUARTER OF SAMPLE		Second-Third Quarters	Second-Fourth Quarters	
Day Range:	190-344	H_0: $\sigma_1^2 = \sigma_2^2$	H_0: $\sigma_1^2 = \sigma_2^2$	
Quarter Sub-sample size:	80	H_1: $\sigma_1^2 \neq \sigma_2^2$	H_1: $\sigma_1^2 \neq \sigma_2^2$	
Quarter Mean:	29.4312	F=1.240419	F=1.305334	
Quarter Standard Deviation:	10.385	$F_{0.10(2), 79, 79} = 1.46$	$F_{0.10(2), 79, 80} = 1.46$	
		Accept H_o of equality	Accept H_o of equality	
THIRD QUARTER OF SAMPLE		Third-Fourth Quarters		
Day Range:	345-505	H_0: $\sigma_1^2 = \sigma_2^2$		
Quarter Sub-sample size:	80	H_1: $\sigma_1^2 \neq \sigma_2^2$		
Quarter Mean:	30.5437	F=1.052333		
Quarter Standard Deviation:	9.32443	$F_{0.10(2), 79, 80} = 1.45$		
		Accept H_o of equality		
FOURTH QUARTER OF SAMPLE				
Day Range:	506-730			
Quarter Sub-sample size:	81			
Quarter Mean:	31.6543			
Quarter Standard Deviation:	9.08962			

Table 23(b): Tests for differences in variance.
Sample: 62 USs. Data divided up approximately into fifths.

Powers of all tests exceed 0.90.

(Effect size based on upper and lower standard deviations of 12 and 8 respectively. Power read from "Master Table", Kraemer and Thiemann, 1987.)

FIRST FIFTH OF SAMPLE		First-Second Fifths	First-Third Fifths	First-Fourth Fifths	First-Fifth Fifths
Day Range: 0 to 189	0-158	$H_0: \sigma_1^2 = \sigma_2^2$	$H_0: \sigma_1^2 = \sigma_2^2$	$H_0: \sigma_1^2 = \sigma_2^2$	$H_0: \sigma_1^2 = \sigma_2^2$
Fifth Sub-sample size:	64	$H_1: \sigma_1^2 \neq \sigma_2^2$	$H_1: \sigma_1^2 \neq \sigma_2^2$	$H_1: \sigma_1^2 \neq \sigma_2^2$	$H_1: \sigma_1^2 \neq \sigma_2^2$
Fifth Mean:	27.67	F=1.00882	F=1.23975	F=1.06879	F=1.18020
Fifth Standard Deviation:	9.56	$F_{0.10(2), 63, 64} = 1.53$	$F_{0.10(2), 63, 63} = 1.53$	$F_{0.10(2), 64, 63} = 1.53$	$F_{0.10(2), 63, 61} = 1.53$
		Accept H_o of equality	Accept H_o of equality	Accept H_o of equality	Accept H_o of equality
SECOND FIFTH OF SAMPLE		Second-Third Fifths	Second-Fourth Fifths	Second-Fifth Fifths	
Day Range: 190 to 344	159-263	$H_0: \sigma_1^2 = \sigma_2^2$	$H_0: \sigma_1^2 = \sigma_2^2$	$H_0: \sigma_1^2 = \sigma_2^2$	
Fifth Sub-sample size:	65	$H_1: \sigma_1^2 \neq \sigma_2^2$	$H_1: \sigma_1^2 \neq \sigma_2^2$	$H_1: \sigma_1^2 \neq \sigma_2^2$	
Fifth Mean:	30.73	F=1.25069	F=1.07822	F=1.16987	
Fifth Standard Deviation:	9.52	$F_{0.10(2), 63, 64} = 1.53$	$F_{0.10(2), 64, 64} = 1.53$	$F_{0.10(2), 64, 61} = 1.53$	
		Accept H_o of equality	Accept H_o of equality	Accept H_o of equality	
THIRD FIFTH OF SAMPLE		Third-Fourth Fifths	Third-Fifth Fifths		
Day Range: 345 to 505	264-395	$H_0: \sigma_1^2 = \sigma_2^2$	$H_0: \sigma_1^2 = \sigma_2^2$		
Fifth Sub-sample size:	64	$H_1: \sigma_1^2 \neq \sigma_2^2$	$H_1: \sigma_1^2 \neq \sigma_2^2$		
Fifth Mean:	28.99	F=1.15996	F=1.46316		
Fifth Standard Deviation:	10.64	$F_{0.10(2), 63, 64} = 1.53$	$F_{0.10(2), 63, 61} = 1.53$		
		Accept H_o of equality	Accept H_o of equality		
FOURTH FIFTH OF SAMPLE		Fourth-Fifth Fifths			
Day Range: 506 to 730	396-546	$H_0: \sigma_1^2 = \sigma_2^2$			
Fifth Sub-sample size:	65	$H_1: \sigma_1^2 \neq \sigma_2^2$			
Fifth Mean:	30.45	F=1.26138			
Fifth Standard Deviation:	9.88	$F_{0.10(2), 64, 61} = 1.53$			
		Accept H_o of equality			
LAST FIFTH OF SAMPLE					
Day Range: 506 to 730	547-730				
Fifth Sub-sample size:	62				
Fifth Mean:	32.05				
Fifth Standard Deviation:	8.80				

As is evident from Tables 23(a) and 23(b), nowhere on the standardized domain could the null hypothesis of equal variance be rejected at p = 0.10. Additionally, the powers of all the tests were high against the generally accepted value of 0.80 (see Appendix 4.1, Section 4.1.2.2). In accordance with the standards accepted by this study, therefore it was assumed that the variance was approximately constant over the domain. For the division of the sample into four the average variance was calculated as 94.8339 and for the division into five, 94.0652. The standard deviation of S was thus found to be approximately 9.72 over the two-year domain.

5.2.2 The testing of Hypothesis $H_{1(a)}$

The first research question formulated in Chapter 2 was:

How, in general, does a user's satisfaction with a system change over time?

(see Chapter 2, Section 2.4.1).

Hypothesis $H_{1(a)}$, developed in Chapter 3 (see Section 3.3.1.4) in response to this was as follows:

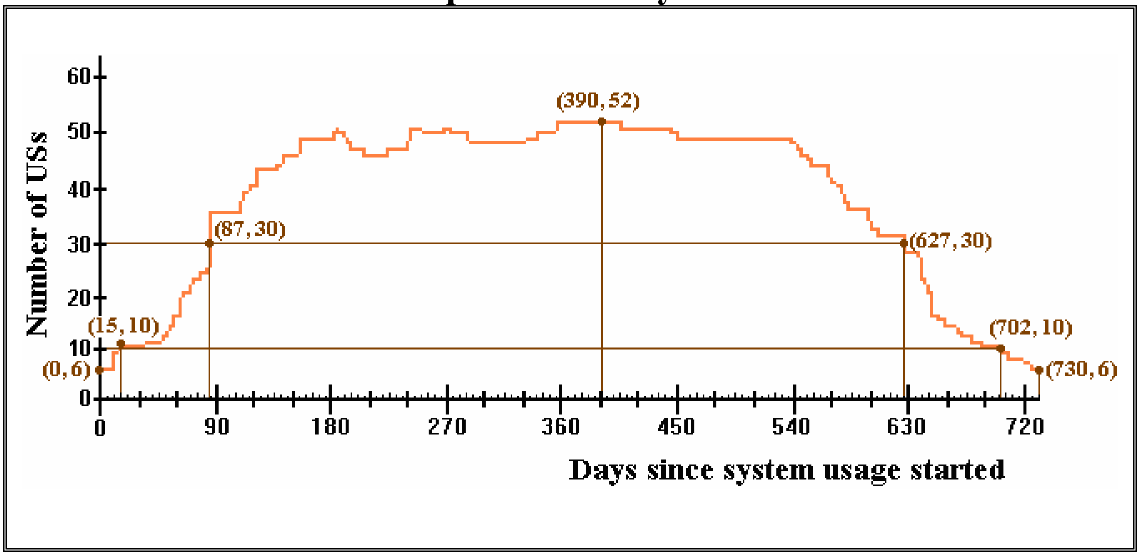
$H_{1(a)}$:	During the life of a US, user satisfaction will generally rise with time as the user gains experience with the system.

The first test for this was to fit the S-Score time series with the best-fitting rectilinear graph (see ABC in Figure 5), using the method of least squares (Zar, 1999). The segment BC is that portion of this line which occurs on the standardized domain. From this, it is evident that the sample data exhibit an upward secular trend of 7.00 S-Score units, from S = 27.06 to S = 34.06 over the standardized domain (0 to 730 days inclusive).

While the above procedure supports hypothesis $H_{1(a)}$, it cannot alone demonstrate it conclusively for the population of USs. Further statistical analysis was thus undertaken. This took the form of determining the mean-S for each day in the domain, plotting the daily mean-S values and examining the resultant curve for patterns and trends. Although only 3 to 7 readings were taken for each US, all intermediate points were estimated by linear interpolation (see Chapter 4, Sections 4.4.3 and 4.4.4) for each day, from -116 to 847 inclusive. The interpolation was carried out by a computer program written to produce a full set of S-Score data for each day in this domain, and over all 62 USs in the sample (see Appendix 5.2, Section 5.2.1). It was also designed to plot the curve of mean-S on time, given as Figure 7.

Of prior significance, however, was the number of USs contributing data at various points along the domain, since this impacted the statistical tests used. A graph of these is given in Figure 6. There it is evident that at no time were all 62 USs contributing data anywhere on the domain, the maximum being 52 at, and in the neighbourhood of day 390. Generally organizations were asked to make systems available for research which had been operational for 90 days or fewer. In most cases, this obligation was met, so that 35 or more of the USs studied were in existence by day 90. Of further significance is the trailing off of the number of USs from day 538 (49 USs) until it drops below the 30-mark at day 627. This varying number of contributing USs changes the conditions of most of the statistical tests used in this study across the domain and so needed to be included in the discussion of key results. This is especially true when the number of active USs dropped below the sample size of 10, as this impacted the non-parametric tests used. At first sight, the loss of 25 USs appears high. However, as mentioned in Chapter 4, Section 4.4.1, they only contributed one to two readings each, causing a loss of 27 readings for S out of an initial 360.

<u>Figure 6</u>: Number of User-Systems active on each time-domain day. Sample: 62 user-systems.



These considerations led the present study to investigate the distribution of US lives and hence infer the expected life-times of USs in general. US lives in the sample were estimated as the time at which the last reading was taken, before the US had terminated. As most readings were made about 90 days apart, the US lives could be recorded as up to about 90 days longer than the values used. In practice, however, this was largely avoided, as USs which terminated did so within a two weeks of the final reading. This was verified, since the termination date was recorded on page 3 of the associated copy of the SSS; 'the date on which usage (of the system) stopped' (see Appendix 1.2). Based on the estimate of the final reading, US lives in the sample ranged from 184 to 847 days, with a mean of 563.6 days and a standard deviation of 170.0 days. Based on these figures and the estimated US life-values, a Chi-square test for normality was conducted. As per the method outlined in Appendix 4.1, Section 4.1.3, five equiprobable cells were set up with expected US life frequencies of 0.2 each. Statistics calculated while performing this test are given in Table 24(a). From this it is evident that the null hypothesis of normality could not be rejected, even at significance levels of far greater size (and hence less significance) than have been laid down as standards for this study (see Appendix 4.1, Section 4.1.2). For an effect-size index of w = 0.40, the test exhibits a power in excess of .80, which further supports the null hypothesis of normality (see Appendix 4.1, Section 4.1.2).

Table 24(a): Test for normality of US life-times.
Sample: 62 USs, over 5 equiprobable cells.

Calculated χ^2 =	16.710
$\chi^2_{0.995,\,59}$ =	34.770
$\chi^2_{0.005,\,59}$ =	90.715
No grounds to reject null hypothesis of normality even for p very much greater than 0.10. **The power of this test exceeds .80 for an effect-size index of w = 0.40** (Table 7.3.16 of Cohen, 1988, p 235. Also, see Appendix 4.1, Section 4.1.3.1)	

Table 24(b): Determination of 99% Confidence Interval for the mean population US life-time.
Sample: 62 USs.

Mean Life =	563.6 days
StdDev =	170.0 days
Sample Size =	62
$t_{(.005,\,61)}$ =	2.6589
99% Confidence Interval for US population mean	**= 506.2 – 621.0 days**

It was possible further to set a confidence interval for the mean of US lives in general (see Appendix 4.1, Section 4.1.5 for the procedure). The 99% confidence interval for the population mean was found to be: [506.2, 621.0] (see Table 24(b) for details). If the upper limit of 621.0 is taken as an estimate of the population mean (in fact, it is improbably high), and the sample standard deviation of 170.0 as an estimate of the population standard deviation, (allowable if the sample size exceeds 30, see Zar 1999), then 74% or more population USs terminate by the 730th day after their initiation. This finding can be restated by saying that 26% or fewer users make use of a given system developed by a given analyst for longer than two years; itself a significant finding. At first sight this might be explained in terms of the policies of some organizations to review all their systems periodically. However, the reason for US termination was recorded in all cases (see Appendix 1.2, bottom of Page 3 of the SSS instrument). The reason for termination was never given that it was the result of an organizational review. Most typically, USs terminated because the user had left or changed jobs within, the organization.

5.2.3 Characteristics of the mean-S curve

As noted in Section 5.2.2, this section addresses more generally the first research question. A graph of the mean-S on time was plotted over the domain from day 0 to day 730. This is given in Figure 7, where it is seen to exhibit a number of features. First, it fluctuates during the first 111 days of system usage (see Figure 7, arc **abcdef**). From **f** to **h** a gentler rise and fall, peaking at **g** (183 days, S=29.72), occurs. Over the arc **hi** the mean-S rises in a linear fashion from **h** (288 days, S=28.59) to **i** (538 days, S=31.46). Thereafter, fluctuations occur again, peaking at **j**, **l** and **m**. As the period approaches the end of the time domain (day 730) the mean-S reaches a global maximum value at **n** (day 717, mean-S = 34.22). The last results over the arc **mn** may be misleading, since at **m** (day 684, mean-S = 31.45) only 11 USs were still in operation. At **n** (day 717, mean-S = 34.22) the sample had dropped to 8 USs, which is fewer than the minimum of 10 required for the non-parametric tests used (see Appendix 4.1, Section 4.1.8.1). The curve of user satisfaction versus time exhibits an upward secular trend from mean-S = 23.00 to mean-S = 33.42. This offers some agreement with the secular trend demonstrated in Figure 5, for S = 27.04 to S =34.08, although once again it hardly gives statistical grounds to accept hypothesis $H_{1(a)}$.

5.2.4 The mean-S studied as a time series

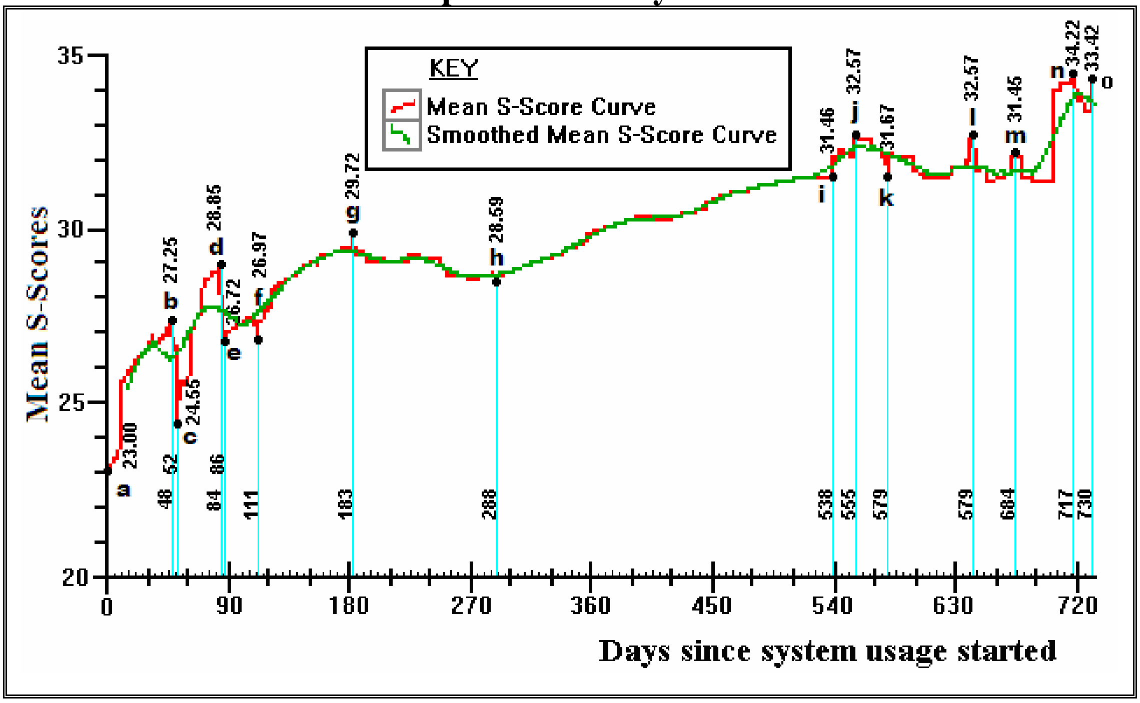
As users started interacting with their systems randomly throughout the year, this study rejected *a priori* the existence of any seasonal variation (see Appendix 4.1, Section 4.1.10 for the meaning of "seasonal variation"). It is clear, however, that irregular variation as described in Appendix 4.1, Section 4.1.10, is present to some extent. This is made evident by the first two dominant peaks **b** and **d** and the jagged nature of the curve (Berenson and Levine, 1986).

To obtain a clearer understanding of any underlying trend in the mean-S time-series and so as not to exclude the possibility of an underlying curvilinear relationship, a 31-day moving average was used to smooth the curve (for details of the method, see Appendix 4.1, Section 4.1.10). The periods of 31 days were chosen:

1. To study phenomena approximately on a month-by-month basis; and
2. To simplify the graphing procedure by providing a single median day (the 16th) in each 31-day period.

According to Prins (2005) and Berenson and Levine (1986) this would eliminate much of the random fluctuation and some of the cyclical variation, associated with any 31-day period. The first period for which the S-Scores were averaged was from Day 0 to Day 30 inclusive, with mid-point, Day 15. This means that the smoothed curve commences at Day 15 (see Figure 7). Another program (see Appendix 5.2, Section 5.2.2), similar to the previous one, was written to produce the smoothed curve and to output the smoothed S-Score data.

Figure 7: Mean-S on Time: Smoothed and unsmoothed curves. 31-day moving averages used to create smoothed curve. Sample: 62 user-systems.



From Figure 7 it is evident that the smoothed curve coincides credibly with the unsmoothed curve of mean-S-values. The smoothed curve supports some of the features of the unsmoothed curve, most particularly the local maxima and minima, and the upward near-linear region **hij**. It will be noted that these features occur approximately over the same regions of the time domain in both curves, and provide some support for their generalisability. A further observation is, that in the sample of USs tested, more variation in the mean satisfaction curve occurs in the beginning and end regions of the graph (**ah** and **io** respectively) than in the middle region (**hi**) (see Figure 7).

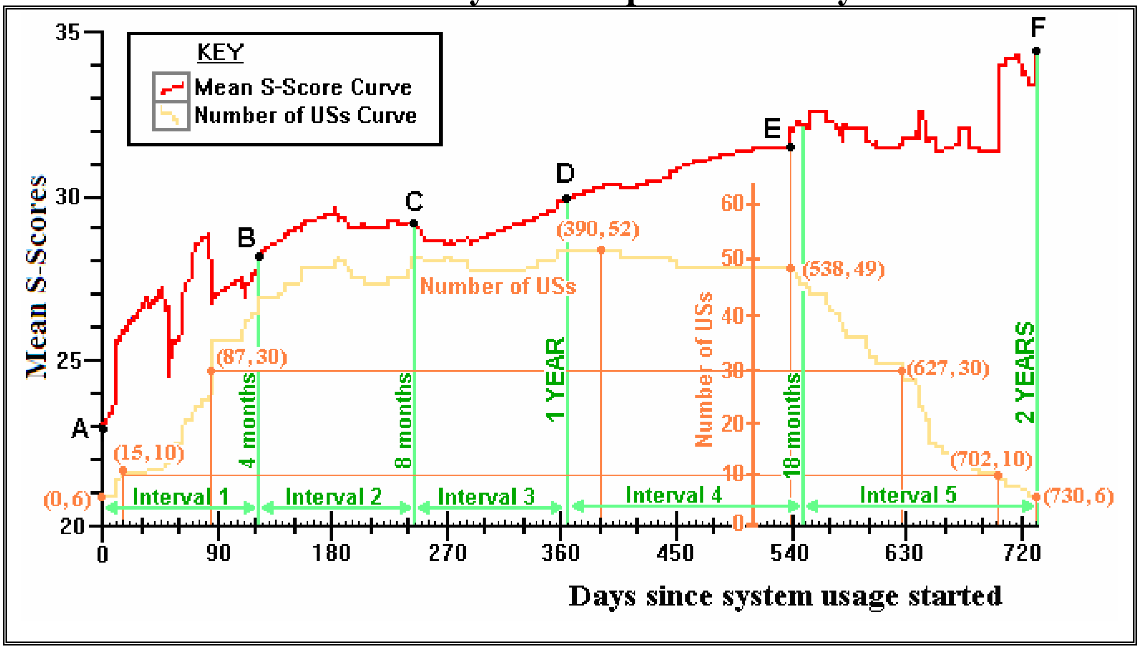
Figure 7 also suggests that at least some of the fluctuation at the start and towards the end of the domain can be ascribed to a low sample size (less than 30 USs before day 87 and after day 627). Indeed, the least fluctuation occurs between these days where the sample size reaches a maximum of 52 active USs. The question was thus, whether features such as the sudden drops **bc** and **de** corresponded to a sharp change in numbers of active USs. This proved not to be the case. The points **b** and **c** had all but one US in common. When this single case was eliminated, the mean-S at **b** was found to be 25.11

over 12 USs instead of 24.55 over the original 13: the feature otherwise remained. It was further found that all USs contributing to **d** also contributed to **e**, and vice versa: hence this feature could not be discredited on similar grounds either.

One also needs to note that the rising sample size in the early part of the domain is inherently different from the falling sample size in the latter part. In the early phase (see Figure 6, day 0 to day 87), all 62 of the sample USs were live or about to go live, but collection of data had not commenced for them all. This was consistent with the request to organizations to make systems available for analysis which had become active within a period of 90 days (see Chapter 4, Section 4.2.9). In the case of the drop-off in active USs over the period, days 627 to 730 inclusive, USs were actually terminating. The reasons for their termination quite clearly included drops in user satisfaction (though not necessarily the sole cause), and yet this level of terminal dissatisfaction escaped measurement. Discussion of further results needed to bear this in mind, and the present study was careful to do so. The original data at points **j**, **k**, **l**, **m**, **n** and **o** (see Figure 7) were examined and US data not common to both were struck out. These points then assumed mean-S values which were very close to one another, each being within 0.5 of S=32.5. In short, this study could not reject the hypothesis that the fluctuations were owed to anything other than small sample size; at least, not on the preceding criteria. USs were terminating in increasing numbers from day 538 until only 6 remained at day 730 (see Figure 6). The conclusion was reached therefore that while fluctuations may occur for reasons other than small sample size in the early phases of US life, the same could not be said for the late stages. It was found that those USs which terminated towards the end of the time domain often did so because the user, for whatever reason, had suddenly become highly dissatisfied with the system. This would cause an instant drop in mean-S, as means are over-affected by extreme values (see Appendix 3.1, Section 3.1.4). Once such a system terminated, however, a large component of the low mean-S would vanish, with a corresponding sudden up-turn in its value. As a precaution, therefore, this study kept sample size in focus for all further analysis and discussion of the data.

A difficulty found with this phase of the analysis in the light of the preceding discussion, is the question of detail. The data are examined on a quasi daily basis, and the level of precision may hide underlying trends, notwithstanding the smoothed curve presented in Figure 7. On closer examination of the mean-S curve, it was evident that the two-year time domain could be meaningfully divided into intervals, on each of which the curve exhibits different behaviours. On this basis, the first year was divided into three intervals of four months, while the second year was divided into two intervals of six. The divisions are shown in Figure 8 in green.

Figure 8: Composite: Mean-S and Number of active USs on time. Shows three 4-month zones in Year 1 and two 6-month zones in Year 2 of the analysis. Sample: 62 user-systems.

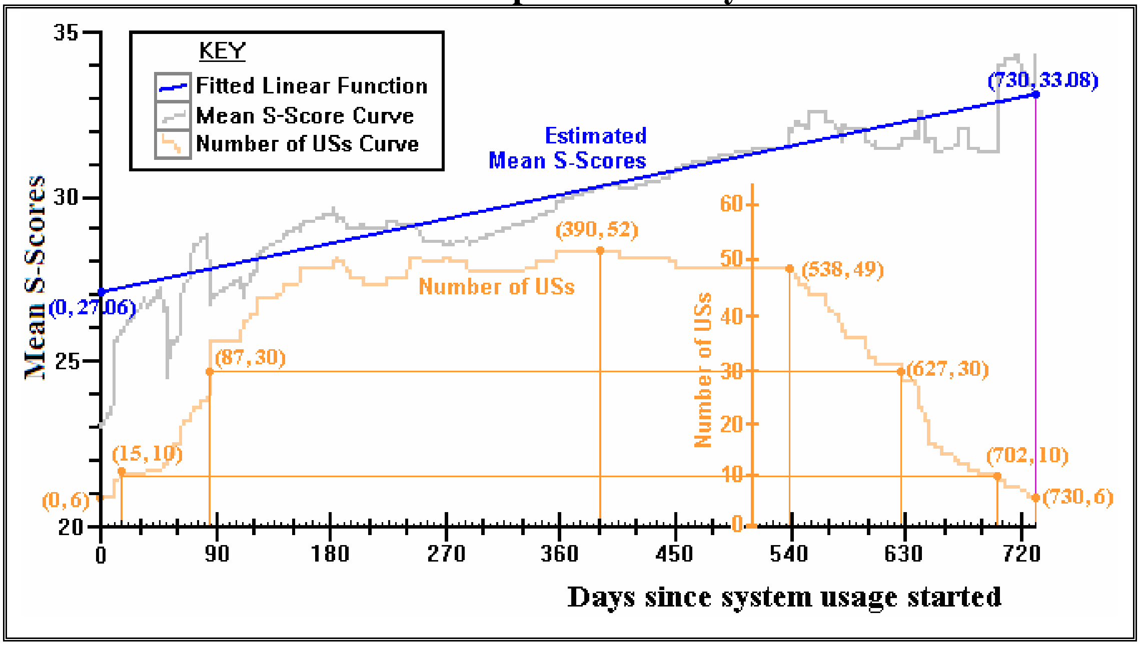


It is evident from Figure 8 that the mean-S curve fluctuates in an irregular manner over arc AB on Interval 1, suggesting that this is a period of uncertainty in a user's attitude towards a new system. In Interval 2, the curve does not display as much irregular variation, but presents the less extreme, convex form BC. In the third interval, the mean-S curve exhibits a yet shallower concave form, before it commences on an approximately upward linear trend (CD). This linear trend continues through most of Interval 4 (DE). Just before this ends, however, the number of USs contributing data begins to fall. Immediate, concurrent irregularity in the mean-S curve occurs (EF). This behaviour is continued throughout the last six-month interval until the end of the second year of the domain. Some of this erratic behaviour is explained in terms of USs with extreme S-Scores suddenly being removed from the analysis. This has a rather extreme effect on the size of the mean (see Appendix 3.1). Not all USs terminate because of dissatisfaction, however. Some end simply because the user leaves the firm or changes jobs within the existing organization. This makes it possible for USs in which the systems are highly satisfactory to the user, to terminate; a condition which clearly has the reverse effect compared to the loss of a US with lots of unsatisfactory factors. All in all, therefore, erratic behaviour of S should be expected when USs in general are steadily terminating. For those USs which survive Interval 5, satisfaction continues to climb in a linear fashion. In short, during the last half of Interval 5 there is a dichotomy between USs terminating because of perceived, negative factors, and those for other reasons. A few which survive longer, will continue with increasing satisfaction ratings as users continue to gain experience with them.

5.2.5 The secular trend in the S-data tested empirically

Unlike the best-fitting line exhibited in Figure 5, the one described in this section was fitted using only the original data (320 readings) occurring on the standardized domain (day 0 to day 730 inclusive). With the aid of the Microsoft® Excel® package, the slope of the best-fitting sample regression line was found to be 0.00756. Over the 320 data which fall on the standard domain, this is significant at $p = 0.005$ (for the test, see Appendix 4.1, Section 4.1.13). An observation is that the slope itself is very small. However, one should reflect that the S-Score has a very small range (-12 to 40 in this study) compared with the time-domain of 731 days. It was thus deemed possible for the regression line slope to be small, and yet highly significant. The same package was used to find the vertical intercept of the regression line, which was S = 27.06000. It was then possible to produce this line, which is exhibited as the blue line graph in Figure 9.

Figure 9: Composite: Best Rectilinear Function fitted to S-data on time, together with Mean-S and Number of Active User-Systems Curves. Sample: 62 user-systems.



A further test, which did not require an assumption of linearity, was employed. This was to examine the means of sample S-data at the ends of arcs covering portions of the curve. Although only one pair of points required testing to show the existence of this trend, three pairs in all, **ao**, **bn** and **cm** (see Figure 7) were investigated. Bartlein's (2005) two-sample test, which requires an assumption of population independence, but not of equal population variance was used. It is formulated in Appendix 4.1, Section 4.1.11. The calculations were carried out by a program specially prepared for this study (see Appendix 5.3), and for a selection of pairs of points describing arcs of the original mean-S curve (see Figure 7, unsmoothed curve). In each case, the objective was to test for a significant difference of day-population means at the time-ordinates of the ends of the arcs. The question of population independence was addressed by ensuring that the sub-sample pair was independent; that is, that no single US contributed S-data to both sub-samples. The results are given in Table 25(a). Although the test is robust to non-normality in populations (Zar 1999), the result was cross-checked using the Mann-Whitney test for location (for details, see Appendix 4.1, Section 4.1.9), this being even less affected by population distribution. The results are corroborated (see Table 25(b)), with the third being confirmed at p=0.01; a stronger level of significance than for the corresponding t-test. As all the results were significant at either the 0.05 or 0.01 levels, it was not necessary to perform power tests (see Appendix 4.1, Section 4.1.2.2).

Table 25(a): The use of the difference of means t-test to investigate the secular trend in the Mean-S curve.
Sample: 62 USs. Letter arc references: see Figure 7.
(Each test is one tail, the direction as per the relevant arc of the Mean-S curve.)

Arc	Sample Sizes		Calculated t-Value	Degrees of Freedom	Critical t-Value	Significant
	n_1	n_2				
ao	6	6	2.18427	5	1.94300	at p = 0.05
bn	11	8	3.11685	7	2.99800	at p = 0.01
cm	13	11	1.85464	10	1.79600	at p = 0.05

Table 25(b): The use of the Mann-Whitney test to confirm the secular trend in the Mean-S curve.
Sample: 62 USs. Letter arc references: see Figure 7.
(Each test is one tail, the direction as per the relevant arc of the Mean-S curve.)

Arc	Sample Sizes		Calculated U- or Z-value	Critical U- or Z-value	Significant (Mann-Whitney)	Comparison with t-test (Table 25(a))
	n_1	n_2				
ao	6	6	U = 32	U=29	at p = 0.05	same
bn	11	8	U = 78	U=77	at p = 0.01	same
cm	13	11	U = 116	U=112	at p = 0.01	more significant

One should note that the pairs of points **bn** and **cm** were tested as a cross-check for the most extreme pair, **ao**. It is not a requirement that all three cases are supported together, and no such claim is made. The significant upward results provided by both the t-test and Mann-Whitney test support hypothesis $H_{1(a)}$, as does the regression-gradient test discussed above. In accordance with the standards accepted (see Appendix 4.1, Section 4.1.2) $H_{1(a)}$ was supported by this study.

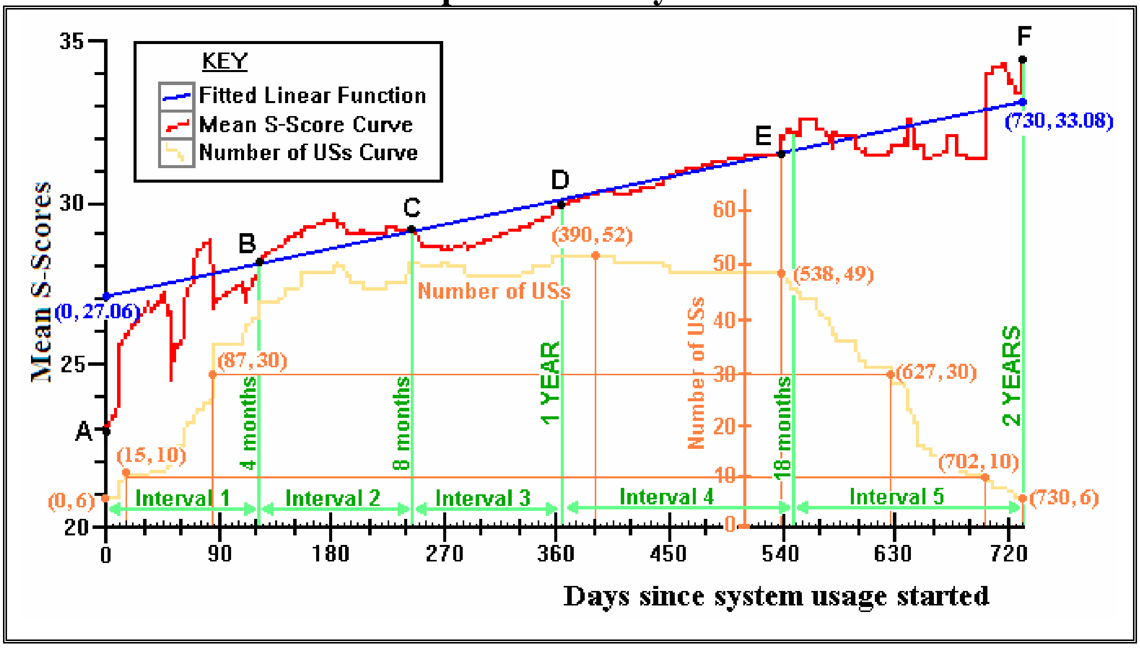
A curvilinear function which might fit the S-data better than the regression line already determined (Figure 9) was sought. For this, the latter could be regarded as the first step in the iterative process to find the best-fitting polynomial function (see Appendix 4.1, Section 4.1.10 for Zar's (1999) procedure). In accordance with this procedure, the best-fitting quadratic function was tried next. Hyams' (2003) Curve Expert® package was used to determine this function from the non-interpolated data on the 0-730-day domain. Using the F-Statistic as described in Appendix 4.1, Section 4.1.10, it was found that the quadratic function did not provide a significantly better fit than the linear function at p =

0.10 (see Table 26). In accordance with the recommendation that the next higher order polynomial should then be tried (see Appendix 4.1, Section 4.1.10), the best cubic function was fitted next. This did not prove to be a better fit than the quadratic model at p = 0.10. This study therefore concluded that the linear model was the best option as a fitted time-series curve for S. It was thus retained as a basis for further discussion of trends in the data. However, this study continued to focus on both the mean-S curve and the changing sample size over the domain. This is reflected in the composite diagram, Figure 10.

Table 26: The use of the F-statistic test to determine the best fitting polynomial curve for the estimate of Mean-S on Time.
<u>Sample</u>: 62 USs.

Model		F-statistics (calculated and critical)	Significance
Linear			
Regression Sum of Squares	679.6098		
Residual Sum of Squares	30542.6818		
Residual Mean Square	96.0462		
Quadratic		**Quadratic/Linear**	
Regression Sum of Squares	875.0474	F=2.04	
Residual Sum of Squares	30522.9930	$F_{0.10(1), 1, 319} = 2.72$	**not** at p = 0.10
Residual Mean Square	95.9843		
Cubic		**Cubic/Quadratic**	
Regression Sum of Squares	960.7377	F=0.89	
Residual Sum of Squares	30515.9074	$F_{0.10(1), 1, 319} = 2.72$	**not** at p = 0.10
Residual Mean Square	95.9620		

Figure 10: Composite summary: Mean-S curve, Fitted Rectilinear function and Number of USs curve, together with time zones. Sample: 62 user-systems.



5.2.6 General inferences regarding the source data and population

From the sample of 62 USs researched in this study, inferences of various strengths can be made about system evolution and its relationship to user satisfaction. For instance, it was concluded that the population of S generally exhibits an upward secular trend over the first two years of system usage. This was demonstrated empirically at the p = 0.005 significance level (see Section 5.2.2). Over the same period, the standard deviation of S remains approximately constant at a value of about 9.72 (see Section 5.2.1). Only 6 of the USs remained in existence on day 730, suggesting that all but some 10% of USs cease to exist within two years of their initiation. What could be inferred at p = 0.005, was that at most 26% of the population USs remain in existence for two years or more (see Section 5.2).

Over the domain, a number of features were evident in the sample of USs. First, there were three undulations in the mean-S, as exhibited in Figure 7; **abc**, **cde** and **efgh** (see Section 5.2.5). The present study did not find that they *do* occur in the population, but rather that they *can* occur in US samples of similar size to the research sample. Support for this possibility was strengthened by the 31-day moving average smoothed curve (see Figure 7), which shows the existence of less extreme fluctuations on similar regions of the domain. Of significance also is the near linear reduction of active USs from day 538 to day 730; that is, over the last six months or so of the two-year time window (see Figure 10). Over the same period, however, the mean-S continues to rise erratically.

The acceptance of hypothesis $H_{1(a)}$ (see Section 5.2.5) implies that an upward rectilinear graph is a suitable candidate as a time-series trend-line for S. The best-fitting rectilinear graph was studied together with the best-fitting quadratic and cubic functions (see Section 5.2.5). Neither the quadratic model nor the cubic model tested to be of a significantly better fit than the rectilinear model at $p = 0.10$ (see Section 5.2.5). This study thus concluded that the trend in mean-S (satisfaction) is best modeled as a straight line with a positive gradient. A summary of the findings in the whole of Section 5.2 is given in Table 27.

Table 27: Summary of findings: Section 5.2.
Sample: 62 USs.

Finding	Significance	References
The variances and standard deviations of the S-values are approximately constant over the 0-730-day time domain. The constant standard deviation exhibits an average of 9.72 S-units.	Null hypothesis of equal variances could not be rejected at p = 0.10. Power > .90.	Section 5.2.2 Table 23(a) Table 23(b)
Hypothesis $\mathbf{H_{1(a)}}$ supported. It states: *During the life of a US, user satisfaction will generally rise with time as the user gains experience with the system .*	Null hypothesis rejected at p = 0.01.	Section 5.2.5 Table 25(a) Table 25(b)
The estimated lives of sample USs tested to be normally distributed with mean, 563.6 days, and standard deviation, 170.0 days	Null hypothesis of normality not rejected at values of p far higher than 0.10.	Section 5.2.2 Table 24(a)
Confidence interval for mean life of USs determined as [506.2 days, 621.0 days].	Confidence level: 99%.	Section 5.2.2 Table 24(b)
26% or fewer USs survive for longer than two years.	Based on taking upper confidence limit of 99% confidence interval as an estimate for the population mean.	Section 5.2.2
Slope of best-fitting sample regression line found to be 0.00756, hence a non-constant linear function was assumed to be a credible candidate as the most appropriate model for the data.	Significant at p = 0.005.	Section 5.2.5
The greatest variation in the mean-S curve occurred in the first 4-month interval of the USs lives (AB). This reduced over the next two 4-month intervals, settling down to become ascending and approximately linear (BC and CD). During the first 6-month interval of the second year, the upward, approximately linear trend continues (DE). Before the last 6-month interval, however, (day 538), the curve becomes erratic as the number of USs declines (EF)	Determined by observation.	Figures 7 and 8 Section 5.2.4
The best-fitting polynomial function was found to be a rectilinear curve with equation: **S = 27.06000 + 0.00756 x Day**	Quadratic and Cubic models rejected at p = 0.10 as significantly better than the Linear model.	Section 5.2.6 Table 26

5.3 The overall relationship between the cognitive styles of the analyst and user, and the users' overall perceived satisfaction with the system

The second research question given in Chapter 2 was:

> ***Does the cognitive differential between analysts and users (Kirton's (1999) 'cognitive gap') yield advance predictions of overall user satisfaction with a given system?*** (see Section 2.5)

The hypotheses $H_{2(a)}$ to $H_{2(d)}$ and $H_{3(a)}$ to $H_{3(d)}$ required calculation of Kendall-t values and tests of their significance (see Chapter 3, Tables 16(b) and 16(c)). According to Kendall (1970), 10 or more distinct points need to be available so that the associated test statistic has an approximately standard normal distribution (see Appendix 4.1, Section 4.1.8.1). For these hypotheses, therefore, the present study focused on a domain restricted to days 15 to 702 inclusive, which exhibited this requirement.

Based on the four descriptive statistics discussed in Chapter 3, Section 3.3.2.2, this study identified four corresponding hypotheses $H_{2(a)} – H_{2(d)}$, thus:

$\mathbf{H_{2(a)}}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***minimum*** S-Score exhibited by the user during the SU's life.

$\mathbf{H_{2(b)}}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***maximum*** S-Score exhibited by the user during the SU's life.

$\mathbf{H_{2(c)}}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***median*** S-Score exhibited by the user during the SU's life.

$\mathbf{H_{2(d)}}$	There is a negative association between the analyst/user cognitive gap (difference in KAI score), and the ***mean-S***-Score exhibited by the user during the SU's life.

The cognitive differentials were determined as the absolute values of the differences between the analyst and user KAI scores. The association between these and the S-Score statistics were determined as Kendall-t_a values, which were then tested for significance (see Appendix 4.1, Section 4.1.8). Table 28 gives the results of this analysis for the 62-user sample. To establish as complete a picture as possible, linear correlations were determined and tested for significance along with the associations as given in Table 28. This effectively gave eight results; two for each hypothesis.

While the correlation coefficients could be determined using the Microsoft® Excel® spreadsheet package with its attendant statistical functions, the Kendall-t case a is not supported by this package. A computer program was thus written to determine Kendall-t_a values, and is given in Appendix 4.3. Its verification is described in Appendix 4.4. For details of the associated statistical methods used, see Appendix 4.1, Sections 4.1.7 and 4.1.8. Associations and correlations other than those hypothesized were carried out in an effort to seek unpredicted relationships between various cognitive style (KAI) measures and user satisfaction (as S-Scores). Of these, all tested insignificant at $p = 0.10$ except for those of the absolute Analyst-User KAI difference, on three of the four descriptive statistics (Median, Mean and Maximum). It is thus only these tests which are discussed further.

5.3.1 The analyst-user cognitive gap and its relationship to overall user satisfaction: discussion of results

When considering the relevance of an association or correlation, at least two factors need to be taken into account. The first is its *statistical significance* and the second is its *actual distance from zero*. Statistical significance implies a result that would render the chance of independence in the parent population *sufficiently unlikely* to suggest a relationship in that population (see Appendix 4.1, Sections 4.1.7.1 and 4.1.8.1). As discussed in Appendix 4.1.2 this is a matter of precedent rather than statistics, the precedent being set at $p = 0.05$ or less. In other words, the null hypothesis of independence is rejected if there is only a 5% chance or less that it could be true. For $0.05 < p \leq 0.10$, hypotheses alternative to independence are considered only to be weakly supported or indeterminate (see Appendix 4.1.2, Tables 38 and 39). The actual distance from zero, or effect size, is important. A small absolute value of r can test highly significant on account of a large sample size, even though the correlation is negligible (see Appendix 4.1, Sections 4.1.7.1 and 4.1.8.1).

On the basis of this discussion, Table 28 contains results which are significant at values of $p = 0.01$, $p = 0.05$ or $p = 0.10$ respectively. However, the sizes of the sample statistics do not suggest that the corresponding population parameters they estimate (τ or ρ) are very far from zero. In Appendix 4.1, Section 4.1.7, the significance of the size of the correlation coefficient is discussed. There it is suggested that for $-0.8 < \rho < 0.8$ the rectilinear correlation is weak, and negligible for $-0.3 < \rho < 0.3$. For the Kendall-τ, Section 4.1.8 of the same Appendix shows that for $-0.2 < \tau_a < 0.2$ the data are at most 60% discordant or concordant: that is, not very far from 50%, which is the point of independence. It thus rates values within this range as being weak in terms of their size. In other words, even if t_a in this range tests significant, meaning that the null hypothesis of independence is rejected, it estimates a value of τ_a which is close to zero anyway. In short, the results are weak, for even the one which tests significant at p = 0.01 is only 0.2041 in magnitude, yielding a maximum discordance of just over 60%. Thus even if τ were exactly -0.2041, this value of τ would not mean any great departure from independence in the population.

Table 28: Associations (as Kendall t_a-values) and Correlations for KAI scores on S-Scores: Sample = 62 Users.

Table 28(a): Associations (as Kendall t_a-values)	**Kendall association and test statistic**		**Significant* at**		
Measures	**t_a**	**$z(t_a)$**	**p=0.10 ?**	**p=0.05 ?**	**p=0.01 ?**
Absolute analyst-user **KAI Difference** on **Minimum** S-Score	-0.0714	-0.8236	**No**	**No**	**No**
Absolute analyst-user **KAI Difference** on **Median** S-Score	-0.1941	-2.2374	**Yes**	**Yes**	**No**
Absolute analyst-user **KAI Difference** on **Mean-S**-Score	-0.1660	-1.9113	**Yes**	**Yes**	**No**
Absolute analyst-user **KAI Difference** on **Maximum** S-Score	-0.2041	-2.3661	**Yes**	**Yes**	**Yes**

Table 28(b): Correlations (as Pearson r-values)	**Pearson correlation & test statistic**		**Significant* at**		
Measures	**r**	**Student t(r, 60)**	**p=0.10 ?**	**p=0.05 ?**	**p=0.01 ?**
Absolute analyst-user **KAI Difference** on **Minimum** S-Score	-0.1007	-0.8224	**No**	**No**	**No**
Absolute analyst-user **KAI Difference** on **Median** S-Score	-0.2157	-1.7944	**Yes**	**Yes**	**No**
Absolute analyst-user **KAI Difference** on **Mean-S**-Score	-0.1926	-1.5942	**Yes**	**No**	**No**
Absolute analyst-user **KAI Difference** on **Maximum** S-Score	-0.2400	-2.0088	**Yes**	**Yes**	**No**

Weak though the best of these results may be, they do provide evidence of direction and a possible explanation as to why some IS researchers may have found cognitive style of little relevance to IS, in the past. When it comes to which descriptive statistic is best suited to compare with the cognitive differential, the results suggest that the minimum has no significant association or correlation. Hypothesis $H_{2(a)}$ was thus not supported by this study, for either the association or correlation statistic. This means that there is no evidence, based on this test, that the minimum satisfaction level and the cognitive differential are related.

The other hypotheses were either supported (at $p = 0.05$ or 0.01) or weakly supported (at $p = 0.10$). In short there is evidence of a weak relationship between the cognitive differential (absolute analyst-user KAI difference) and the median, mean and maximum S over the two-year time domain. This study thus concluded that the size of the cognitive differential does have a negative impact on overall user satisfaction, but that this effect is modest. It also suggests a possible reason for the failure of other research to identify the impact of cognitive style in IS research and practice, as noted by Huber (1983) and intimated by Carey (1991). That the present study could even find the weak relationships discussed is probably a function of the fact that it was carried out over a significant period of time (no prior study found in the literature had essayed to do this) and could thus obtain meaningful descriptive statistics for the overall satisfaction measure. One should note, however, that these results do not properly find that the cognitive differential has a weak impact on user satisfaction. The reason could be that the hypotheses $H_{2(a)}$ to $H_{2(d)}$ posit too simplistic a model of the impact of cognitive style. As the next section shows, the significance of cognitive style varies over the time domain, and in certain regions, is highly significant.

5.4 The impact of the analyst-user cognitive gap and individual cognitive styles on user satisfaction over time

This part of the analysis did not set out to test hypotheses $H_{3(a)}$ to $H_{3(d)}$, (see Table 29) at single points in time. It rather, as discussed in Chapter 3, Section 3.3.2.3, attempted to test where exactly on the domain each hypothesis is supported or not supported (see also Chapter 3, Figure 3.1). In short, the quest was to find out where the effects predicted by each hypothesis hold, and how strongly they hold, over the entire time domain.

Table 29: The third research question and attendant hypotheses, $H_{3(a)}$ to $H_{3(d)}$.

Research Question 3:
Does the cognitive differential between analysts and users yield advance predictions of overall user satisfaction with a given system?
(see Chapter 2, Section 2.5)

Hypotheses:

$H_{3(a)}$ The absolute cognitive gap, taken as |Analyst's KAI score – User's KAI score| is negatively associated with the S-Score at any given point in time during the SU's life.

$H_{3(b)}$ The cognitive gap measured as the Analyst's KAI score less the User's KAI score is negatively associated with the S-Score at any given point in time during the SU's life.

$H_{3(c)}$ The user's cognitive style measured as the User's KAI score generally *increases negatively* during the SU's life.

$H_{3(d)}$ The analyst's cognitive style measured as the Analyst's KAI score is negatively associated with the S-Score at any point in time during the SU's life.
(see Chapter 3, Section 3.3.2.3)

Curves of t_a values were determined using the program given in Appendix 5.5. As previously mentioned, significance tests for 10 or more bivariate data based on Kendall's (1970) standard normal statistic z(t) are reliable (see Appendix 4.1, Sections 4.1.8 and 4.1.8.1). On days where the user sample dropped below 10, therefore, the program was designed to ignore the data. It thus effectively processed S-data over the restricted domain discussed earlier, from day 15 to day 702 inclusive. On each of these days, the active US sample size was 10 or more.

The four KAI-based factors (cognitive models) used for each system reflected hypotheses $H_{3(a)}$ to $H_{3(d)}$, and were:

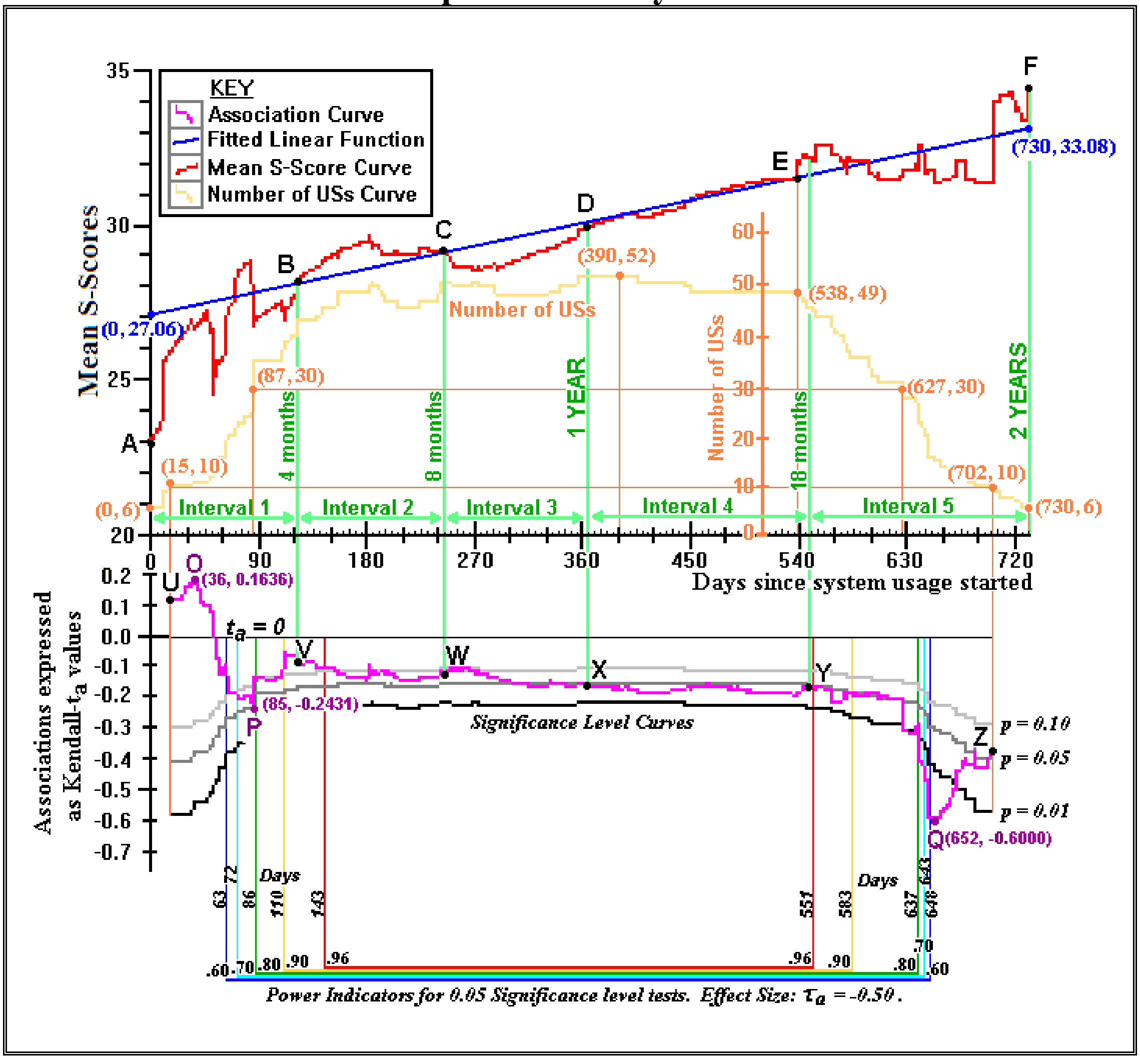
- The absolute analyst-user cognitive gap (difference in KAI scores);
- The cognitive gap calculated as Analyst KAI less User KAI;
- The User KAI; and
- The Analyst KAI.

The relevance of each cognitive model as listed above, was calculated as Kendall t_a values for the associations between each of these and the user S-Scores for each day (15 to 702) of the domain for which 10 or more USs were in operation. The results were then graphed for each hypothesis (see Figures 11 to 14).

A general explanation of these composite figures is as follows. To each of the four graphs of t_a on time, the curves developed in Section 5.3 were added, together with the five time intervals (Intervals 1 to 5). This was facilitated by the fact that the mean-S and associated curves exhibit positive ranges, while any relevancy curve of t_a, exhibits mostly negative values. The latter implies that each cognitive model was, in general, either negatively associated with S, or only briefly positively associated with low values. All the associated tests were thus one-tail, negative tail tests (see Figures 11 to 14).

On the same diagrams, curves representing the p=0.10, p=0.05 and p=0.01 significance levels were also drawn. In the hypothetical model given in Figure 3 of Chapter 3, the significance levels are shown as horizontal straight lines. In the case of the real data, however, (see Figures 11 to 14) these tended to be shallow curves, as significance varied depending on how many of the 62 sample USs contributed data. Each significance level curve thus turns downwards at its extremes and is eventually discontinued where fewer than ten S-data existed. In reading the significance of a relevancy curve (purple in colour), if the curve coincides with or drops below a significance curve, the value of t_a is significant at that level. For example, in Figure 14, t_a at P is significant at p = 0.05 but not at p = 0.01. At Q, t_a is significant at p = 0.01, and, of course, at the other two levels as well. Additionally, colour-bar indicators are drawn in to show where on the domain the minimum powers of tests on t_a at the 0.05 significance level, occur. Hence for example, in Figure 11, the key curve is the mauve line in the negative region of the figure and shows the strength with which Hypothesis $H_{3(a)}$ can be accepted or rejected at any point in the time domain. The significance curves and power indicator have been added for this purpose. The red curve represents the mean S for all active USs, on time, while the blue curve is the best-fitting straight line graph to this. The yellow curve represents the number of USs active at points in time over the domain. Figures 12-14 are constructed similarly. The results are discussed for each cognitive model corresponding to each of the four hypotheses $H_{3(a)}$ to $H_{3(d)}$, in Sections 5.4.1 to 5.4.4 respectively.

Figure 11: Relevance of Absolute Analyst-User KAI-Score difference over System usage time, together with the Mean-S Curve. Sample: 62 user-systems.



5.4.1 The impact of the absolute analyst-user cognitive gap on user satisfaction over time (Hypothesis $H_{3(a)}$)

This part of the analysis involves the testing of hypothesis $H_{3(a)}$, which states:

$H_{3(a)}$:	The absolute cognitive gap, taken as |Analyst's KAI score – User's KAI score| is negatively associated with the S-Score at any given point in time during the SU's life.

As discussed above, the analysis sought to find where on the time domain, Hypothesis $H_{3(a)}$ can be supported, and with what strength. To this end, a graph of the relevancy of the absolute analyst-user KAI difference (as Kendall t_a values) on time was plotted and added to the composite of the mean-S and US-number curves as shown in Figure 11 as the purple curve UOPVWXYQZ. As previously mentioned, power indicators for the 0.05 significance level test and effect size of $\tau_a = 0.5$ were also added.

5.4.1.1 Interval 1

The curve of t_a starts at U (15 days) and peaks at O (day 36) with the Kendall-t_a value of 0.1636 (***not*** significant at p = 0.10). Thereafter it troughs (peaks negatively) at P (85 days). The value of t_a at P is -0.2431, which is significant at p = 0.05 and represents a maximum discordance 62% in the pairs of points (see Appendix 4.1, Section 4.1.8). The power of the 0.05 significance-level test was slightly less than the recommended value of 0.80 (see Appendix 4.1, Section 4.1.2.2). After this, the t_a curve rises sharply to point V.

This behaviour coincides with the evident irregular variation of the mean-S curve and the rise of the number of USs contributing data to the analysis (see Figure 11, arc AB). One should bear in mind that the irregular variation by the mean-S curve cannot be totally explained in terms of a smaller sample size (see Section 5.2.4). Previously it was concluded that fluctuations could occur on this interval for reasons of user uncertainty with a new system rather than small sample sizes, in the early phases of US life. In any case, at P the sample size is 26 USs, well above the minimum of 10 prescribed by Kendall (1970) for reliable results. Combining these considerations with the previous observations described in Section 5.3, this study concluded that if users are in a state of uncertainty on Interval 1, they are likely to exhibit abnormal sensitivity to the analyst's cognitive style at some stage in this interval. Further, that this is likely to be manifest as great dissatisfaction if the analyst differs significantly from him/her in cognitive style. This is underpinned by the discussion in Chapter 3, Section 3.3.2.1. There it is conjectured that, where a user and analyst are of similar cognitive style, stress is minimized between the two as each can follow his/her preferred problem-solving style within the dyadic couple (Kirton, 1999, Mullany, 1989). However, if they differ in cognitive style, greater stress will occur. High stress would, according to Herzberg (1968) demotivate any worker and result in their complaining. Such complaints are obviously likely to be more intense than complaints made under a lower stress situation (see Table 14 in Chapter 3).

5.4.1.2 Interval 2

The curve varies between significance and no significance at $p = 0.10$ on Interval 2 (see arc VW in Figure 11). In accordance with the standards accepted by this study (see Appendix 4.1, Section 4.1.2) this meant that the relevancy of the absolute cognitive gap varies between weak significance and no significance on this interval. The power of the 0.05 significance level test is at least 0.90 over this interval and rises to at least 0.96 for most of it. This means that where it is not actually rejected, the null hypothesis is strongly supported everywhere on this interval (see Appendix 4.1, Section 4.1.2.2). Over the same interval, the mean-Satisfaction curve (see arc BC, Figure 11) rises slightly above and then falls back to the best-fitting regression line in C. This led to the conjecture that the user remains rather uncertain of the quality of the system, judged from his/her point of view at this stage. Also, that the absolute cognitive style difference does not impact user satisfaction on this interval. One may conjecture, however, that the user undergoes some form of discovery of the nature of the new system and whether or not (s)he agrees with it's problem-solving approach.

5.4.1.3 Interval 3

On Interval 3, t_a falls from an insignificant value, to where it becomes significant at $p = 0.05$ (see arc WX). Over this interval, it varies in significance between $p = 0.10$ and $p = 0.05$. In other words, the absolute cognitive gap is associated with user satisfaction significantly at $p = 0.05$ for at least some of this interval. It is suggested that a user starts at this stage to obtain a better idea of the cognitive problem-solving nature of their systems and whether or not they are in agreement with them. This is supported by the conjecture that users will have learnt the basics of their systems and be starting to apply them to real world problems. However, the strength of the high power of the 0.05 significance level test, exceeding 0.96, suggests that anywhere where the null hypothesis is supported at $p = 0.05$, it is also strongly supported by the power test. In other words, any support for the alternative hypothesis $H_{3(a)}$ in this interval is weak on account of the high power. The significance of t_a rises steadily over Interval 3 and sustains its significance at the $p = 0.05$ level during the passage to the second year of the domain (see arc WX, followed by XY).

The concurrent behaviour of the mean-S curve over Interval 3 is that it settles down to follow a near-linear upward trend. It thus supports the conjecture above that users are applying their system knowledge to a wider problem field as they have finished learning the system basics.

5.4.1.4 Interval 4

The significance of t_a is maintained steadily during Interval 4 at $p = 0.05$ (see arc XY, Figure 11). In accordance with Appendix 4.1, Section 4.1.2, the null hypothesis of independence is rejected in favour of $H_{3(a)}$ over the entire interval. This implies that, in general, users will be more satisfied with systems built by analysts of similar problem-solving style than of the reverse. The effect, however, is modest with a maximum negative value of -0.1888, at day 554, significant at $p = 0.05$ but representing a maximum discordance of just under 60% in the data. The weakness of the significance is also supported by the high power (≥ 0.96) of the 0.05 significance level test.

The mean-S curve settles down almost exactly to the best-fitting regression line over this interval (see arc DE, Figure 11). This suggests that in general users have reached a stage where satisfaction rises linearly with system experience; an entirely plausible possibility. It also suggests that users are in a stronger position than previously to rate their satisfaction with their systems. This especially after the discussion in Section 3.3.1.1 of Chapter 3, that *user satisfaction* implies a summary of those factors in a user's experience of the system which satiate his/her job needs *after* some experience of using it. The quantitative result, with its negative maximum of $t_a = -0.1888$, suggests that up to about 60% of users at this stage will prefer a system built by an analyst of similar cognitive style. However, the power of the 0.05 significance test remains high, which gives the null hypothesis greater credibility. The cognitive gap was thus not found to impact user satisfaction very strongly on this interval.

5.4.1.5 Interval 5

By Interval 5 (see arc YQZ), the association holds its significance to begin with at p = 0.05. It then, in the second three months of Interval 5 and last three months of the domain, plunges downwards to a value at Q, of t_a = -0.6000, significant at p = 0.01. This represents a maximum discordance of 80% in the associated data pairs on day 652 (see Appendix 4.1, Section 4.1.8 for the formula). It also suggests that the higher the cognitive gap, the less satisfied the user will be in about 80% of all cases at Q, making this reading the most significant result of this section. Thereafter, the curve rises, crossing the 0.01 significance level and terminating in Z on day 702 with a value of -0.3771. This is significant at p = 0.10 and represents a maximum discordance of 69%. On day 698, however, the value of t_a was found to be -0.4000, significant at p = 0.05 and representing a maximum discordance of 70% (see Appendix 4.1, Section 4.1.8 for the formula).

At Q, user dissatisfaction is most strongly associated with the absolute cognitive differential, in an interval where USs are terminating at a steady downward rate (see Number of USs curve in Figure 11). This implies that close to termination, user dissatisfaction is more associated with the absolute cognitive gap than at any other time. The earlier quote from Chapter 3, claiming that *user satisfaction* implies a summary of those factors in a user's experience of the system which satiate his/her job needs *after* some experience of using it, certainly applies in this situation. Users are better qualified to rate their satisfaction with their systems just prior to their cession of system use than at any other time. This is, after all the point at which they have had most experience of the system. It also suggests that at some point during the last three months of a USs life, as many as 80% of users, no matter how experienced they may be with a system, will tend to denounce it and abandon it if the analyst has a significantly different cognitive style from their own.

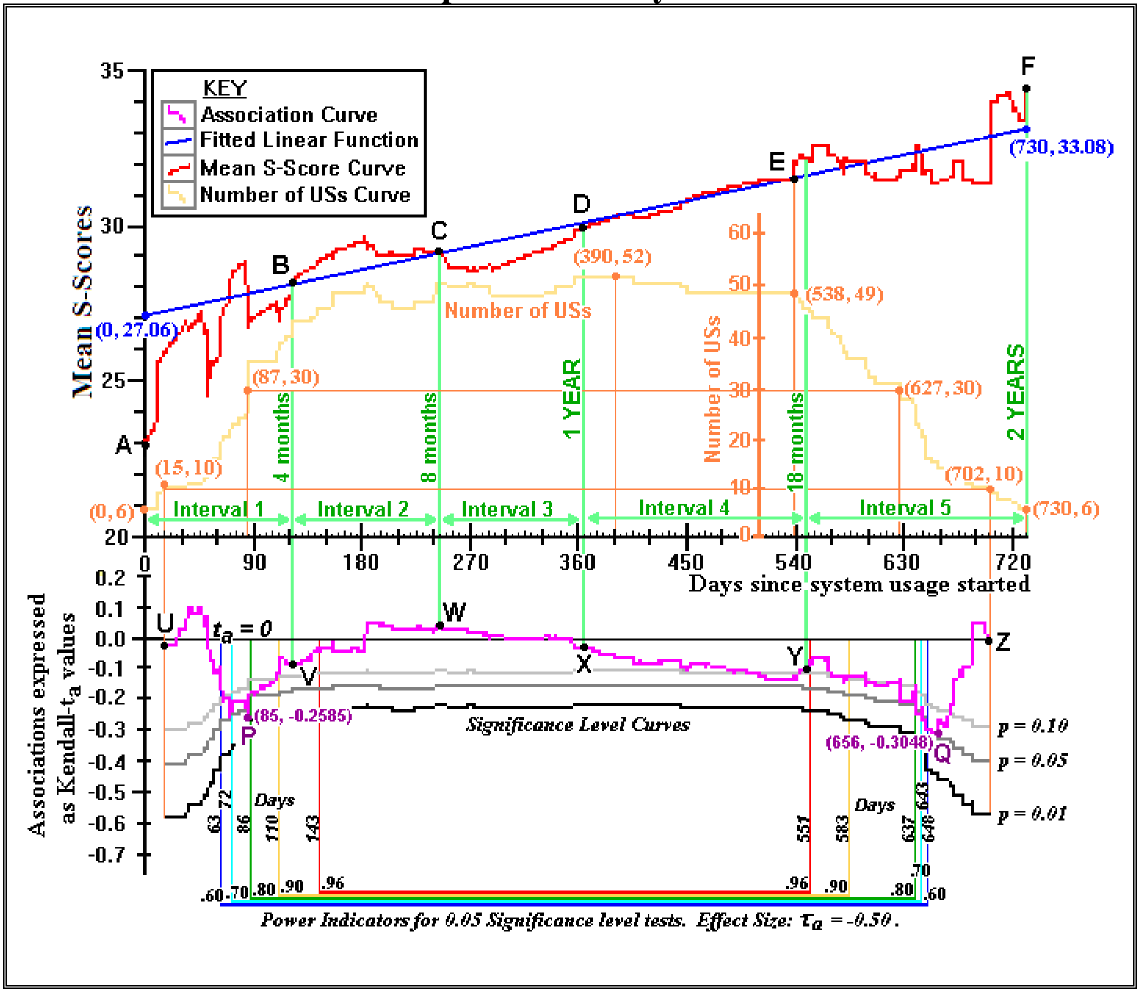
5.4.1.6 Over the whole domain

A further observation is that the absolute cognitive gap impacts user satisfaction in all five intervals of the two-year period and indeed over most of the time domain (see Figure 11). However, the value of t_a only exceeds an absolute value of 0.2 in the neigbourhoods of points P and Q. At P, the implication is that a short period of particular sensitivity to the analyst's cognitive style is likely to occur during the first four months of system usage, and the strength of any accompanying dissatisfaction is associated with the size of the cognitive gap. At Q, when USs are in the process of terminating, the size of the cognitive gap is even more salient than near P. This study found therefore that as USs terminate, dissatisfaction just prior to termination is highly associated (80% maximum discordance at its peak) with the cognitive gap. In other words, most users express their greatest dissatisfaction just prior to US termination with systems developed by analysts of differing cognitive style, the dissatisfaction and cognitive gap being highly negatively associated.

A further examination of the relevancy curve in Figure 11 helps explain the low sizes obtained for t_a for the associations between overall user satisfaction and the absolute cognitive gap (see Section 5.3.1 and Table 28). It was previously conjectured (see Section 5.3.1) that the reason for these low values was that the models proposed by hypotheses $H_{2(a)}$ to $H_{2(d)}$ are too simplistic. After the most recent analysis, the present study could confirm this. The hypotheses $H_{2(a)}$ to $H_{2(d)}$, which posit negative associations between the absolute cognitive gap and the minimum, median, mean and maximum overall user satisfaction, applied to most, if not all of the domain. From Figure 11, the cognitive gap is seen to be low but relevant, at least at $p = 0.10$, almost everywhere on the domain. The only exceptions are in the neighbourhoods of P and Q where $| t_a |$ is much larger (see Figure 11). P and Q are just two points, however, so the *average* relevancy of the cognitive gap over the whole domain would be expected to be significant, but low, as the tests of hypotheses $H_{2(a)}$ to $H_{2(d)}$ suggest.

This study proposes in consequence that an attempt to find an association between a cognitive measure and some measure of user satisfaction, taken as once-off readings from a sample of systems, can expect the result to be significant, but low. This would apply even if the measures of cognitive style and user satisfaction were entirely valid. If one adds to this the many criticisms of existing measures of cognitive style and user satisfaction given throughout Chapter 2, then low and insignificant results are entirely possible. It thus is not surprising that authors such as Huber (1983) and Carey (1991) could find little evidence for the value of cognitive style in IS development or research (see also Chapter 2, Section 2.2.4.1).

Figure 12: Relevance of the Analyst KAI *less* the User KAI over System usage time, with the Mean-S Curve. Sample: 62 user-systems.



5.4.2 The impact of the analyst KAI *less* the user KAI (signed cognitive gap) on user satisfaction over time (Hypothesis $H_{3(b)}$)

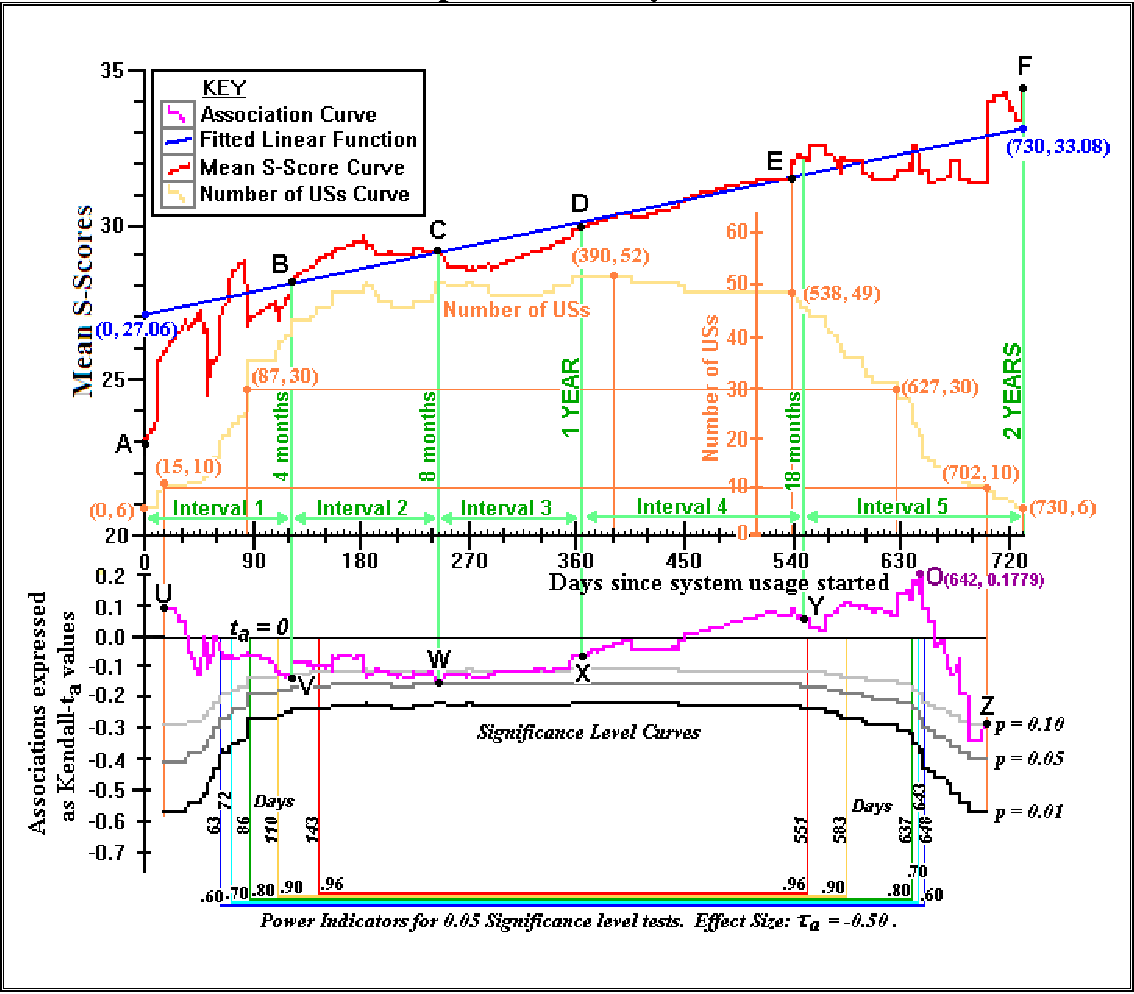
This part of the analysis involves hypothesis $H_{3(b)}$:

$H_{3(b)}$:	The cognitive gap measured as the Analyst's KAI score less the User's KAI score is negatively associated with the S-Score at any given point in time during the SU's life.

A graph of the results for Hypothesis $H_{3(b)}$ is displayed in the composite Figure 12. It should be remembered that this hypothesis examines the relationship between the *signed* or *algebraic* KAI-score differential as opposed to the previous one, which espouses the *absolute* KAI-score difference. Since innovators score higher than adaptors on the KAI (see Chapter 2, Section 2.2.4), this part of the analysis is an enquiry into the impact on user satisfaction when the *analyst* has a higher KAI score (is more innovative) than the *user*, and vice versa The relevance of this differential is exhibited in Figure 12 as the plot UPVWXYQZ. It will be noted that unlike the absolute differential, this one has very little impact on user satisfaction over most of the time domain. As with the absolute cognitive gap, t_a starts weakly positive and then drops to a significantly discordant value of 0.2585 at P. This value, signifying 63% maximum discordance, is significant at $p = 0.05$. The curve then rises into a region of sustained insignificance over Intervals 2 and 3, and most of Interval 4. Thereafter in Interval 5 it drops to a value of 0.3048, which is significant at $p = 0.01$ and represents 65% maximum discordance. While the value of t_a at Q in Figure 12 does fall within all the criteria for rejection of the null hypothesis of independence (see Appendix 4.1, Section 4.1.8), it is a modest result compared with Q in Figure 11.

Both P in Figure 12 and P in Figure 11 coincide time-wise on day 85. Q in Figure 12 and Q in Figure 11 nearly coincide time-wise, occurring on days 656 and 652 respectively. This suggests that both methods of measuring the cognitive gap produce similar negative maxima at more or less the same times. Compared with the absolute cognitive gap model, the lower size of t_a and significance of the signed cognitive gap in the neighbourhood of these points suggests that the impact of the cognitive gap is asymmetric. In other words, users tend to be more dissatisfied with the systems of analysts who are *more innovative* than they are, as opposed to the systems of analysts who are *more adaptive*.

Figure 13: Time-series graph showing Relevance of the User KAI over System usage time, compared to the Mean-S Curve. Sample: 62 user-systems.



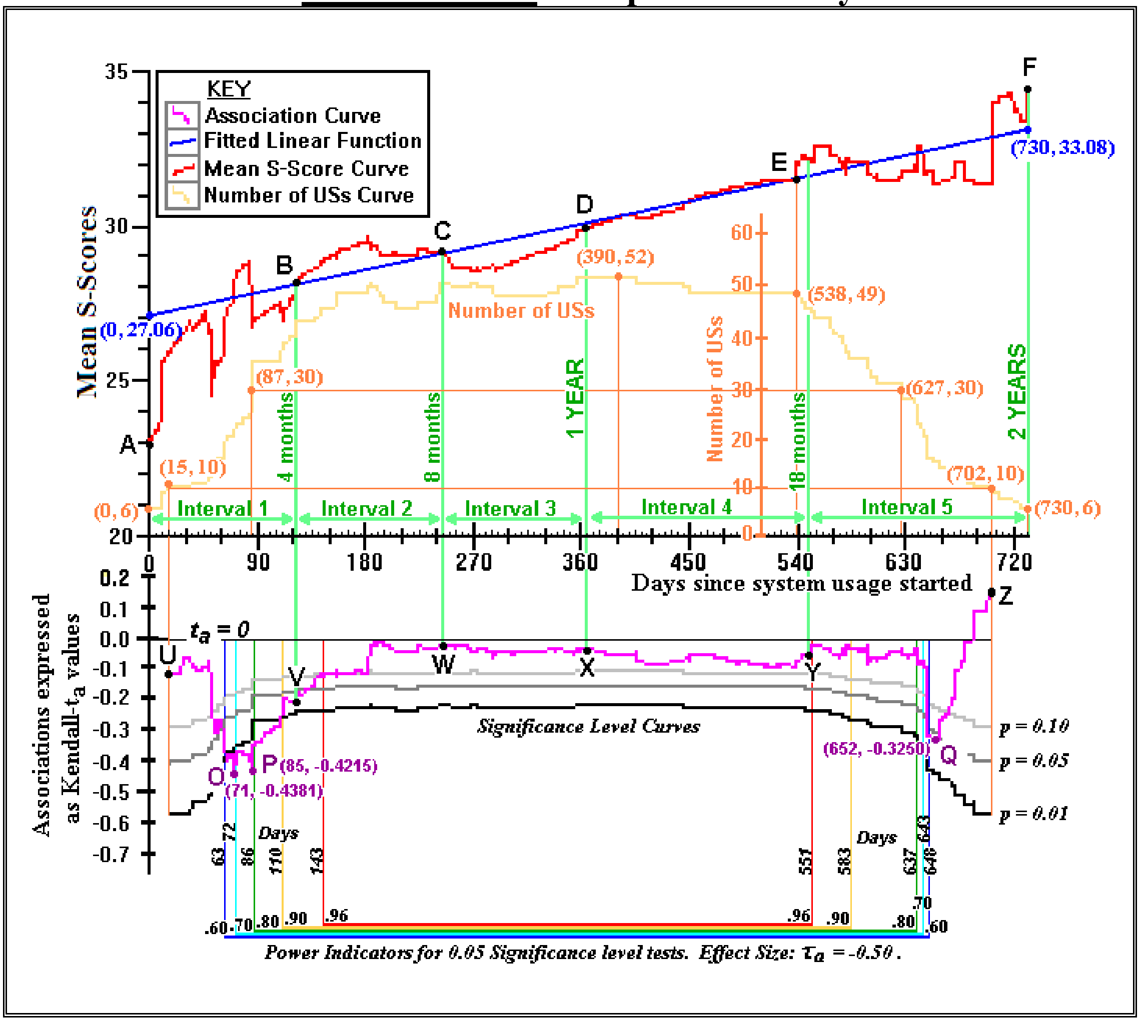
5.4.3 The impact of the user KAI on user satisfaction over time (Hypothesis H $_{3(c)}$)

Testing hypothesis $H_{3(c)}$ over the domain formed the primary objective of this part of the analysis. $H_{3(c)}$ states:

$H_{3(c)}$	The user's cognitive style measured as the User's KAI score generally *increases negatively* during the SU's life.

A graph of the relevance of the user KAI to his/her own satisfaction is displayed in the composite Figure 13. The only place at which t_a tests significant, and then at the indeterminate value of p = 0.10 (see Appendix 4.1, Section 4.1.2.1) is in the vicinity of the terminal point Z. The only region of significance, at p = 0.10, occurs from day 689 to day 699 inclusive. Over this interval t_a varies from -0.3111 to -0.3333, with a negative maximum of -0.3333, signifying maximum discordances of about 66% to 67%. The global maximum for t_a is at O with value 0.1779 (equivalent to a maximum concordance of 59%), which is not significant at p = 0.10. Consequently, this study rejected hypothesis $H_{3(c)}$ over most of the domain. This was supported by the high power of the 0.05 significance test, which remained greater or equal to 0.80 over most of the domain. Considering the indeterminate value of p and the small number of data points in the neighbourhood of Z, this study found no reason to reject the null hypothesis. In short, the user's cognitive style (as his/her KAI-score) was not conclusively found to be associated with user satisfaction anywhere on the domain.

Figure 14: Relevance of the Analyst KAI over System usage time, wih the Mean-S-Score. Sample: 62 user-systems.



5.4.4 The impact of the analyst KAI on user satisfaction over time (Hypothesis $H_{3(d)}$)

The last section of this part of the analysis involved hypothesis $H_{3(d)}$:

$H_{3(d)}$: The analyst's cognitive style measured as the Analyst's KAI score is negatively associated with the S-Score at any point in time during the SU's life.

This section thus examines the impact of the analyst's cognitive style (as KAI-score) over the time domain. A graph of its relevance as t_a–values is displayed in the composite Figure 14. It will be noted that like both the signed cognitive differential and the user's cognitive style, the analyst's cognitive style has very little impact on user satisfaction over most of the time domain. This is also supported by the high power of the 0.05 significance test, which exceed 0.80 over most of the domain. As with the absolute and signed cognitive gaps, however, significant negative peak values for t_a occur in the neighbourhoods of 85 and 652 days. At the close points O and P (days 71 and 85 respectively) t_a assumes values of -0.4381 and -0.4215, both significant at $p = 0.01$, and representing maximum discordances of about 72% and 71% respectively. These two points occur in the neighbourhood of P (85 days) of Figure 11. Also, they exhibit larger negative values than achieved by the absolute cognitive differential at P (Figure 11), the latter being -0.2431. This suggests that innovative analysts contribute more to user dissatisfaction than do adaptive analysts in this region, irrespective of the cognitive style of the user. As previously, the low powers in these regions do not discredit the significance-level tests in these regions, since the null hypothesis is actually rejected.

Q in Figure 14 and Q in Figure 11 coincide time-wise on Day 652. However, the maximum negative relevance of -0.3250 in the former case was significant at $p = 0.05$, compared with the value of -0.6000 at Q in the latter. This comparison suggests that, in the neighbourhoods of P and Q, an innovative analyst's system is found to attract more user dissatisfaction than an adaptive analyst's, irrespective of the cognitive style of the user. It also implies that an adaptive analyst is a better agent for change during the phase of early system use than is an innovative one. As an innovative analyst has a higher KAI-score than a mid-scoring or adaptive user (see Chapter 2, Section 2.2.4), further support is offered for a finding in Section 5.4.2: that, in the vicinity of P and Q

(Figures 5.8 and 5.11) users tend to be more dissatisfied with systems built by analysts who have higher KAI scores than they have. A summary of the key findings in Section 5.4 are given in Table 30.

Table 30: Summary of key findings: Section 5.4.
Sample: 62 USs.

Finding	Significance and Power	References
Interval 1		
The relevancy of the absolute cognitive gap troughs (peaks negatively) at P (85 days). The value of t_a at P is -0.2431, which represents about 62% maximum discordance in the pairs of points (see Appendix 4.1, Section 4.1.8).	Significant at p = 0.05	Section 5.4.1 Figure 11
The above coincides with the evident irregular variation of the mean-S curve and the rise of the number of USs contributing data to the analysis (see Figure 11, arc AB).	Observation	Section 5.4.1 Figure 11
If users are in a state of uncertainty on Interval 1, they are likely to exhibit high levels of dissatisfaction, exacerbated by a significant absolute cognitive gap.	Deduction	Figure 11 Section 5.4.1
As the signed cognitive gap produces a similar negative peak at P, users tend to be more dissatisfied with the systems of analysts who are *more innovative* than they are, as opposed to the reverse.	Deduction	Figure 12 Section 5.4.2
For the signed cognitive gap, t_a starts weakly positive and then drops to a significantly discordant value of 0.2585 at P, signifying 63% maximum discordance.	significant at p = 0.05	Figure 12 Section 5.4.2
The analyst's cognitive style exhibits a significant negative peak value for t_a in the neighbourhood of P at 85 days.		Figure 14 Section 5.4.4
At the close points O and P (days 71 and 85 respectively) the relevancy of the analyst's cognitive style assumes values of -0.4381 and -0.4215, and representing maximum discordances of about 72% and 71% respectively. These are larger negative values than achieved by the absolute cognitive differential at P (Figure 11), the latter being -0.2431.	both significant at p = 0.01	Figure 14 Section 5.4.4
This leads to the conclusion that innovative analysts contribute more to user dissatisfaction than do adaptive analysts in the neighbourhood of P.	Deduced from above	Figure 14 Section 5.4.4
Adaptors tend to be better agents for change during the first four months (Interval 1) of system implementation.	Deduced from above	Figure 14 Section 5.4.4

Table 30: ***Continued from Page 202*****.**

Finding	Significance and Power	References
Interval 2		
The relevancy of the absolute cognitive gap varies between significance and no significance at $p = 0.10$ on Interval 2 (see arc VW in Figure 11).	Observation	Figure 11 Section 5.4.1
Interval 3		
On Interval 3, the absolute cognitive gap is associated with user satisfaction significantly at $p = 0.05$ for at least some of this interval.	Observation	Figure 11 Section 5.4.1
The relevancy of the absolute cognitive gap rises steadily over Interval 3 and sustains its significance at $p = 0.05$ level during the passage to the second year of the analysis.	Observation	Figure 11 Section 5.4.1
The concurrent behaviour of the mean-S curve over Interval 3 is that it settles down to follow a near-linear upward trend.	Observation	Figure 11 Section 5.4.1
Interval 4		
The relevancy of the absolute cognitive gap is maintained steadily during Interval 4 at $p = 0.05$ (see arc XY, Figure 11). This implies that, in general, users will be more satisfied with systems built by analysts of similar problem-solving style than of the reverse. The effect, however, is modest with a maximum negative value of -0.1888, at day 554, but representing just under 60% maximum discordance in the data.	Significant at $p = 0.05$ Power of 0.05 significance ≥ 0.95	Figure 11 Section 5.4.1
The mean-S curve settles down almost exactly to the best-fitting regression line over this interval (see arc DE, Figure 11).	Observation	Figure 11 Section 5.4.1
In general users have reached a stage where satisfaction rises linearly with system experience.	Deduction	Figure 11 Section 5.4.1
The relevancy of the absolute cognitive gap on this interval reaches a negative maximum of $t_a = -0.1888$, suggesting that up to about 60% of users at this stage will prefer a system built by an analyst of similar cognitive style.	Observation and Deduction	Figure 11 Section 5.4.1
Interval 5		
The absolute cognitive gap holds its significance at $p = 0.05$ in the first three months of Interval 5	Observation	Figure 11 Section 5.4.1
In the last three months of Interval 5, the relevancy of the absolute cognitive gap reaches a negative maximum of $t_a = -0.6000$, representing a maximum discordance of 80%.	Significant at $p = 0.01$	Figure 11 Section 5.4.1
At Q, the high relevancy of the absolute cognitive gap is concurrent with the steady termination of USs.	Observation	Figure 11 Section 5.4.1

Table 30: ***Continued from Page 203*.**

Finding	Significance and Power	References
Interval 5: ***continued***		
The relevancy of the signed cognitive gap drops to a value of 0.3048, which represents approximately 65% maximum discordance.	Significant at $p = 0.01$	Figure 12 Section 5.4.2
As in the case of P, this suggests that in the neighbourhood of Q, users are more dissatisfied with the systems of analysts who are more innovative than they are, as opposed to the reverse.	Deduction	Figure 12 Section 5.4.2
In the neighbourhood of Q, an innovative analyst's system is found to attract more user dissatisfaction than an adaptive analyst's, irrespective of the cognitive style of the user.	Observation	Figure 14 Section 5.4.4
Over the whole domain		
The absolute cognitive gap impacts user satisfaction in all five intervals of the two-year period and indeed over most of the time domain. However, the value of t_a only exceeds an absolute value of 0.2 in the neigbourhoods of points P and Q.		
The hypothesis $H_{3(a)}$ to $H_{3(d)}$, which posit negative associations between the absolute cognitive gap and the minimum, median mean and maximum user satisfaction, applied to the entire time domain. This can be explained by Figure 11, where, except in the neighbourhoods of P and Q, the cognitive gap is seen to be low but relevant, at least at $p = 0.10$, almost everywhere on the domain.	Observation, deduction and comparison	Section 5.3 Figure 11 Section 5.4.1
Attempts to find an association between a cognitive measure and some measure of user satisfaction, taken as once-off readings from a sample of systems, can at best expect the result to be significant, but low.	Deduction	Figure 11 Section 5.4.1
The signed cognitive gap does not show relevancy anywhere except in the neighbourhoods of P and Q.	Deduction	Figure 12 Section 5.4.2
The user's cognitive style does not impact user satisfaction, as its relevancy does not test significant at $p = 0.10$ anywhere on the domain.	Observation	Figure 13 Section 5.4.3
In the neighbourhoods of P and Q, an innovative analyst's system is found to attract more user dissatisfaction than an adaptive analyst's, irrespective of the cognitive style of the user.	Observation	Figure 14 Section 5.4.4

5.5 Change in problem severity with time

The fourth research question formulated in Chapter 2 (see Section 2.5) and the attendant hypotheses formulated in Chapter 3, Section 3.4, are given below in Table 31. As mentioned in Chapter 3, Section 3.4, no prior research was found which shed any precise light on how a user's perception of a system problem changes with time. It was thus the aim of this part of the research to employ four possible underlying time-series models, commonly used in the physical and biometric sciences, and to test which of these most closely modeled the change in perceived problem severity as exhibited by the data.

Table 31: The fourth research question and attendant hypotheses, $H_{4(a)}$ to $H_{4(d)}$.

Research Question 4:
How does the user's perceived severity of system problems change with time?

(see Chapter 2, Section 2.5)

Hypotheses:

$H_{4(a)}$: The plot of the perceived severity of a system problem, (R), versus time (t) gives a rectilinear graph with general expression:

$$R = R_0 + m\,t$$

where R_0 is the vertical intercept and m is the rate at which perceived problem severity changes.

$H_{4(b)}$: The plot of the perceived severity of a system problem, (R), versus time (t) gives a quadratic function graph with general expression:

$$R = a\,(t - p)^2 + q$$

where a is the quadratic coefficient (> 0), p is the axis of symmetry and q is the minimum value.

$H_{4(c)}$: The plot of the perceived severity of a system problem, (R), versus time (t) gives a reciprocal function graph with general expression:

$$R = \frac{k}{t + a} + \ell$$

where -a is the vertical asymptote, k is a scaling constant and ℓ is the horizontal asymptote.

$H_{4(d)}$ The plot of the perceived severity of a system problem, (R), versus time (t) gives an exponential decay function graph with general expression:

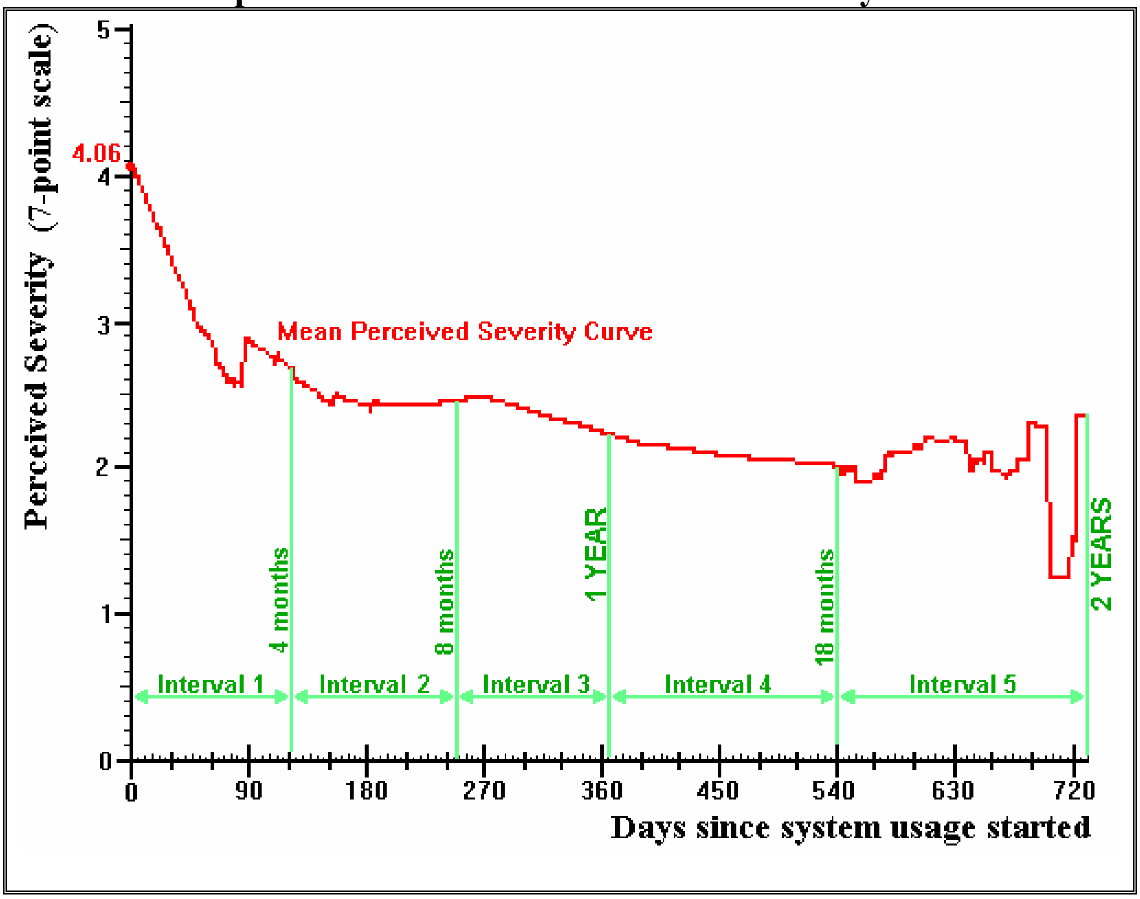
$$R = a\,e^{-kt} + \ell$$

where a is the initial value, k is the constant of proportionality and ℓ is the horizontal asymptote.

(see Chapter 3, Section 3.4)

First, some decision was required as to which USs were suitable for the contributing of problem-factor data to this phase of the study. Eventually only those USs which had contributed at least 5 overall readings were selected. This was to ensure that as many problem-factors as possible provided data representative of at least half of the two-year time domain, and at least three of the five intervals, 1-5 (see Section 5.4.1). On this basis, only forty of the original 62-US sample qualified, which provided a sample of 204 problem-factors. The perceived severity of each problem-factor was estimated on as many days as possible over the 0-730 day domain. This was achieved from the 5-7 readings per US by the use of linear interpolation (see Appendix 5.2). An estimated, average perceived problem severity was then determined for all contributing problem-factors on each day in the domain. The resultant curve for the whole 2-year domain is given in Figure 15. This curve was produced using a program developed for this study and given in Appendix 5.6, Section 5.6.1.

Figure 15: Mean Perceived Severity on System usage time. Sample: 204 Problem-factors over 40 user-systems.



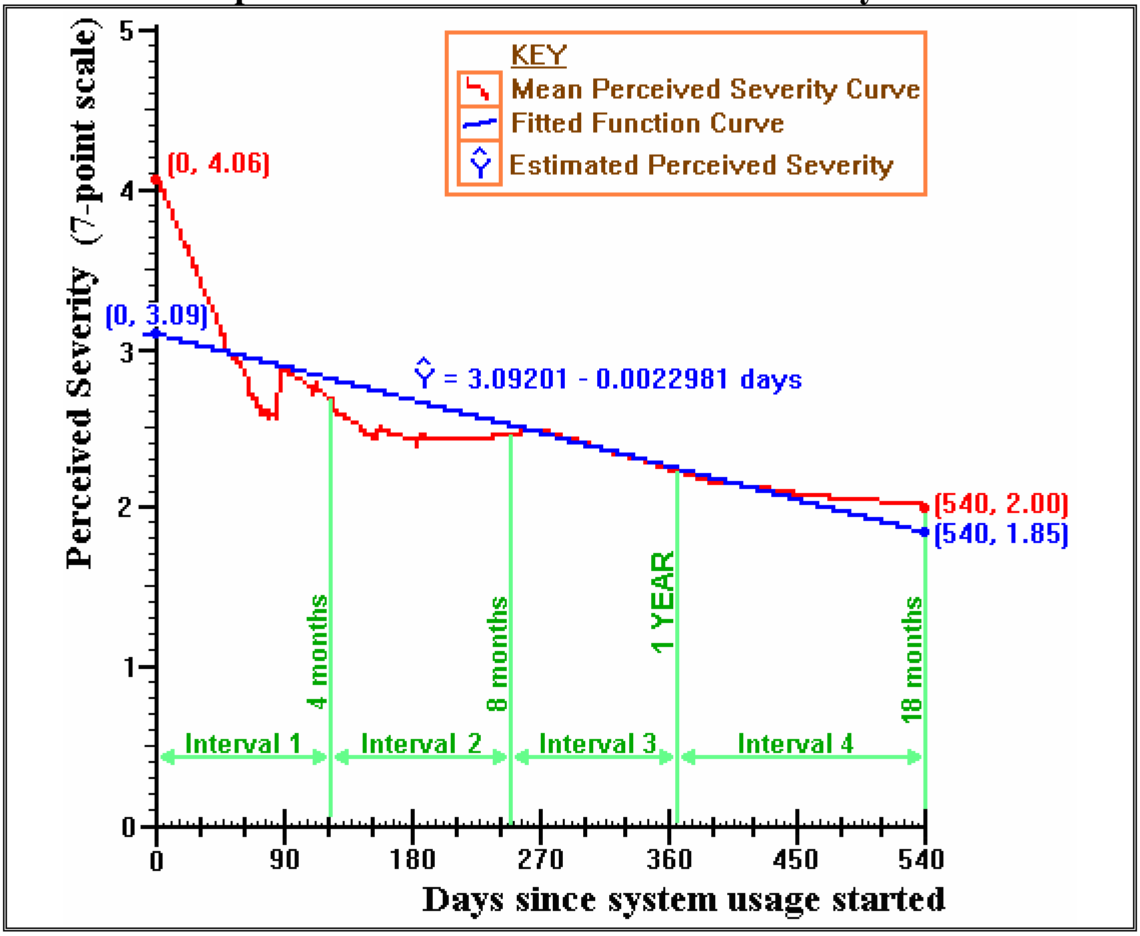
It will be evident from Figure 15 that instability occurs in Intervals 1 and 5, just as with the mean-S curve (see Sections 5.4.1.1 and 5.4.1.5). As noted in in Section 5.4.1.5, the actual mean satisfaction curve becomes erratic on Interval 5, owing to the effects of the sudden deprivation of USs with somewhat extreme S-Scores. On Interval 5, a US may terminate *because* a dissatisfied user manages to get out of using the system further. This factor was judged to be a significant source of error in the present part of the study. Terminating USs cut off the observation of some severe problem-factors becoming salient just prior to US termination and almost certainly contributing to it.

This study tried to fit curves to the entire domain, but these efforts were abandoned after it was evident that no simple function could provide a credible fit. In consequence, this study reduced the attempt to fit curves over Intervals 1 to 4 only; that is, the first 18 months of the original two years. This allowed curves of the four basic models discussed in Chapter 3, Section 3.4 more plausibly to be fit to the data (see Figures 16, 17, 18 and 19). It also facilitated a comparison amongst the models and hence the determination of the best fit.

5.5.1 The linear model

This model, as hypothesized by $H_{4(a)}$ (see Table 31), posits that a user's perception of a problem's severity changes steadily over time. All such functions are straight lines with negative slopes (see Chapter 3, Section 3.4.1). The best-fitting straight line was determined and plotted together with the mean perceived severity curve for the 0-540 day domain by Program 5.6.2 of Appendix 5.6. The result is displayed in Figure 16. From this it is evident that the linear function provides evidence of a downward secular trend of 1.24. However, this is less than the difference between the end points of the data curve, which is 2.06. The fitted graph also deviates quite visibly from the curve on Intervals 1 and 2. The degree of deviation was measured as the least sum of squared residuals (Residual SS) (see Appendix 4.1, Section 4.1.13 for details). The same program, Program 5.6.2 of Appendix 5.6, determined the Residual SS to be 25.0792. The defining equation of this function is given in blue. Further mathematical details are available in Appendix 3.2, Section 3.2.2.

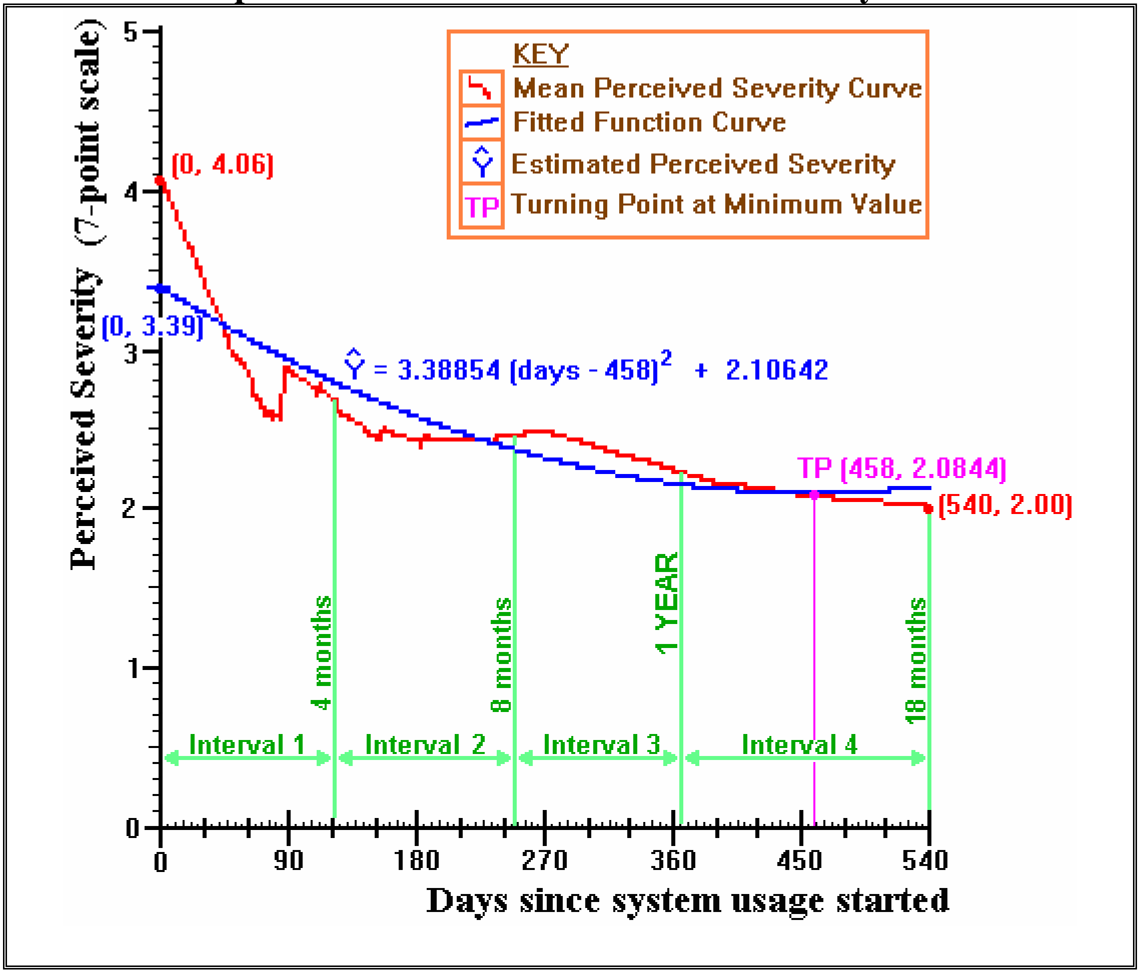
Figure 16: Linear Function, Fit to Mean Perceived Severity on System usage time.
Sample: 204 Problem-factors over 40 user-systems.



5.5.2 The quadratic model

As the Mean Perceived Severity Curve appeared to be curvilinear, a model more of this nature was entertained as a better possible fit (see Chapter 3, Section 3.4.2). The quadratic model is the simplest curvilinear model, and according to Zar (1999), the most used: hence hypothesis $H_{4(b)}$ (see Table 31). The best-fitting quadratic function was determined and plotted on the same set of axes as the mean perceived severity curve for the 0-540 day domain by Program 5.6.3 of Appendix 5.6, as shown in Figure 17 (defining equation in blue). As with the linear function, deviations are evident, not only on Intervals 1 and 2 but also on Interval 3. The residual SS for this regression, however, was found to be 15.4549, suggesting that the quadratic function is indeed a better fit than the linear function (compare with 25.0792, in Section 5.5.1). For details of the quadratic model, see Appendix 3.2, Section 3.2.3.

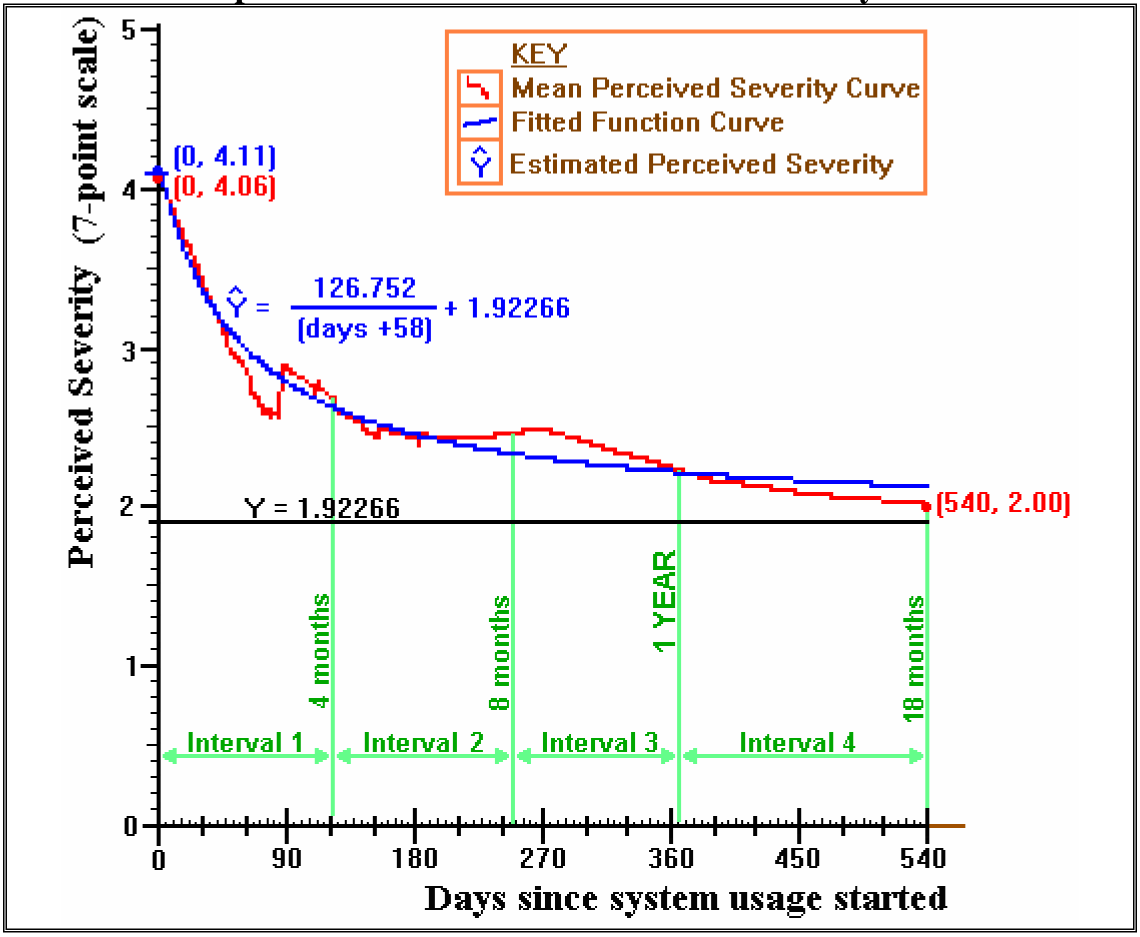
<u>Figure 17</u>: Quadratic Function, Fit to Mean Perceived Severity on System usage time.
Sample: 204 Problem-factors over 40 user-systems.



5.5.3 The reciprocal model

This model, as hypothesized by $H_{4(c)}$ (see Table 31), suggests that a user's perception of a problem's severity decreases over time as an inverse proportion, with the possibility of positional constants. This family of functions, described as *hyperbolae*, are concave curves, descending in this case. For mathematical details, see Appendix 3.2, Section 3.2.4. The best-fitting hyperbola was determined and plotted together with the mean perceived severity curve for the 0-540 day domain by Program 5.6.4 of Appendix 5.6 (defining equation in blue). The result is displayed in Figure 18. It will be noted that the best-fitting hyperbola approximates the Mean Perceived Severity Curve more tightly than the previous two. This is born out mathematically since it exhibits a Residual SS value of 5.18078.

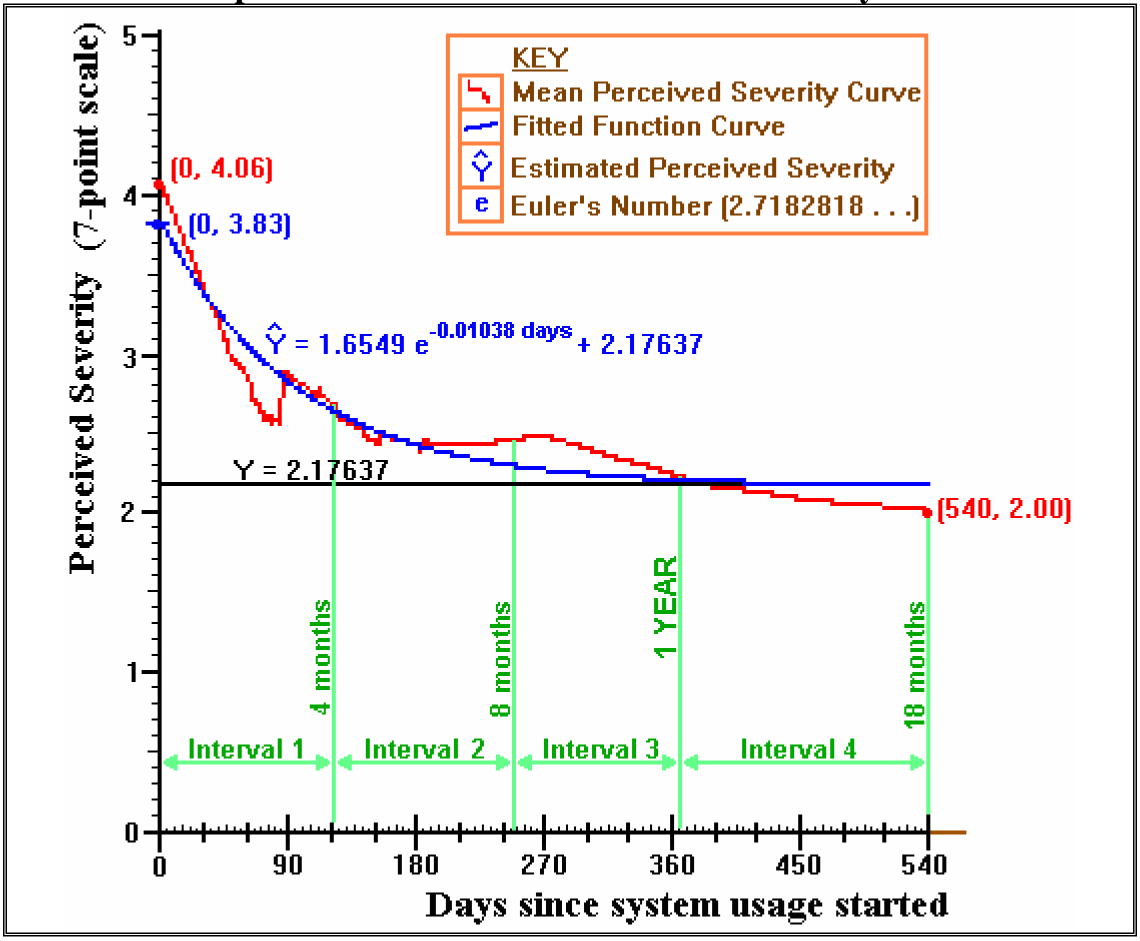
Figure 18: Reciprocal Function, Fit to Mean Perceived Severity on System usage time. Sample: 204 Problem-factors over 40 user-systems.



5.5.4 The exponential decay model

The exponential decay model is hypothesized by $H_{4(d)}$ (see Table 31). The best-fitting function of this kind was determined and plotted on the same set of axes as the mean perceived severity curve for the 0-540 day domain by Program 5.6.5 of Appendix 5.6, as shown in Figure 19 (defining equation in blue). The residual SS for this regression was found to be 8.6004, suggesting that it is a better fit than either the linear or quadratic functions, but not as good as the reciprocal function. For details of this model, see Appendix 3.2, Section 3.2.5.

<u>Figure 19</u>: Exponential Decay Function, Fit to Mean Perceived Severity on System usage time.
Sample: 204 Problem-factors over 40 user-systems.



5.5.5 Statistical comparison of the models

While the residual SS gives a measure of how closely a fitted curve approximates the source data, and thus can show which of a number of functional models fits the data best, it is of interest to know whether or not one model is statistically *significantly* better than another. Without this information, the possibility of discarding the more correct model in favour of one that only chance experimental error has made appear better, increases. This part of the analysis thus turned to the testing of the models, in a sequence from highest to lowest Residual SS, to see if the next in the sequence exhibited a significantly better fit than the last. A test outlined by Zar (1999), using the F-statistic, was employed (for details, see Appendix 4.1, Section 4.1.10). The sequence of tests and the results are given in Table 32.

Table 32: Goodness-of-fit tests to determine the best-fitting of the fitted Linear, Quadratic, Exponential and Reciprocal Functions.
<u>Sample</u>: 541 Estimated Mean Perceived Problem Severities, (one per day of the 0-540 day domain).

Model	Model Statistics	Goodness-of –fit Test	Significance
Linear			
Regression SS	69.6862000000		
Residual SS	25.0792000000		
Residual MS	0.0464429630		
Quadratic		**Quadratic versus Linear**	
Regression SS	79.3105000000	$F_{calculated}$ = 336.2767	
Residual SS	15.4549000000	$F_{0.0005(1), 1, 500}$ = 12.3	
Residual MS	0.0286201852	$F_{0.0005(1), 1, \infty}$ = 12.1	At p << 0.0005
Exponential		**Exponential versus Quadratic**	
Regression SS	86.1650000000	$F_{calculated}$ = 430.3788	
Residual SS	8.6004000000	$F_{0.0005(1), 1, 500}$ = 12.3	
Residual MS	0.0159266667	$F_{0.0005(1), 1, \infty}$ = 12.1	At p << 0.0005
Reciprocal		**Reciprocal versus Exponential**	
Regression SS	89.5846000000	$F_{calculated}$ = 356.4297	
Residual SS	5.1807800000	$F_{0.0005(1), 1, 500}$ = 12.3	
Residual MS	0.0095940370	$F_{0.0005(1), 1, \infty}$ = 12.1	At p << 0.0005

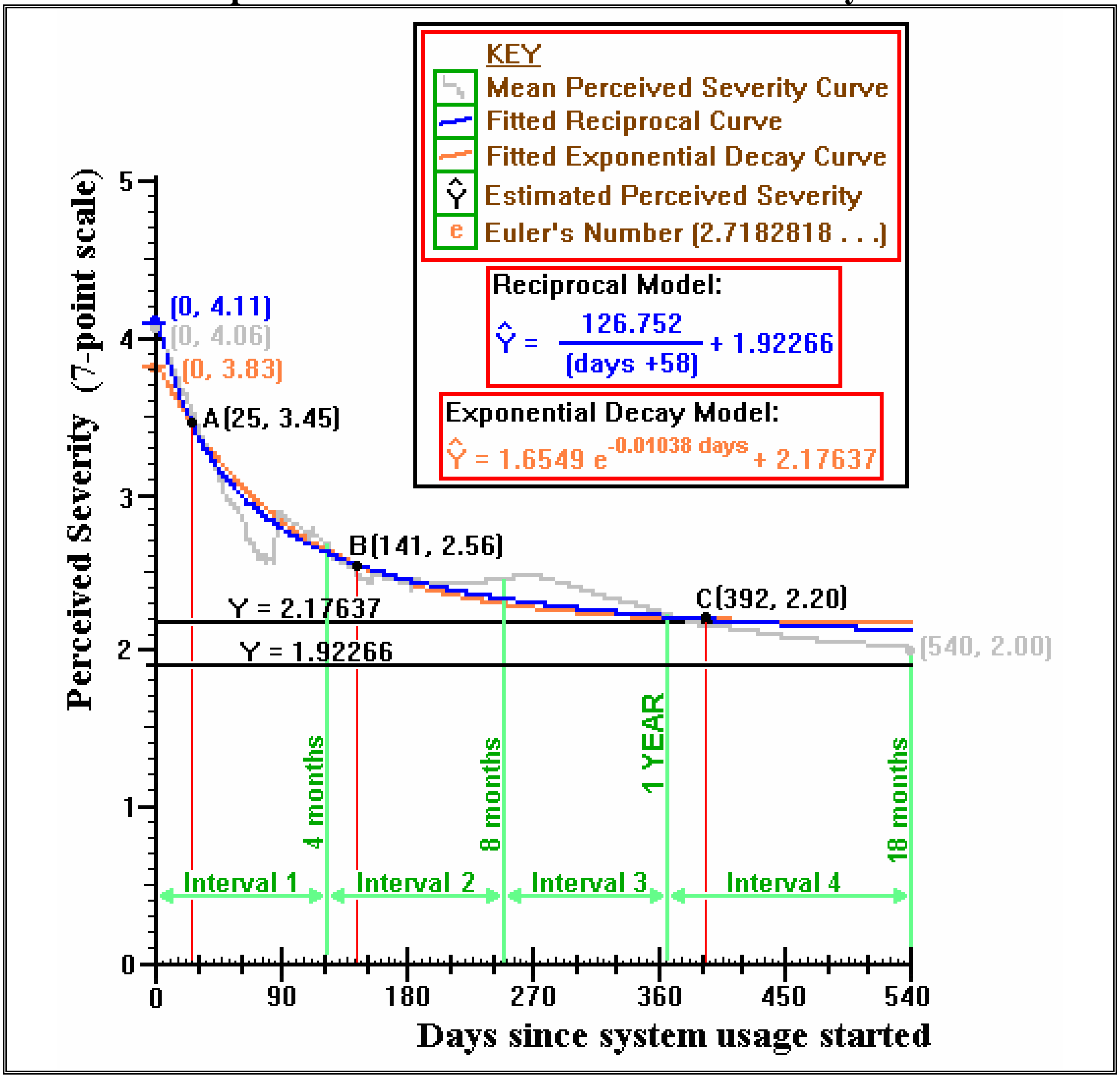
5.5.6 Further comparison of the models

On the basis of the tests shown in Table 32, each function fitted to the mean perceived severity data is highly significantly better than the previous one, with the reciprocal model clearly emerging as the best overall. However, high significance on its own does not imply a meaningful result, as already demonstrated for associations and correlations (see Section 5.3). In all the tests above, the sample size was 541 (for each day of the domain). As discussed in Appendix 4.1, Section 4.1.7.1 and 4.1.8.1, large samples can help weak results to be found statistically significant. Support for the above results was thus sort by observation and argument. The best-fitting linear function contributes only by demonstrating the downward secular trend of the mean perceived severity. After that, neither the eye (see Figure 15) nor the statistical tests above, suggest a particularly close fit. As the data appear to follow a curve, a curvilinear model looked more likely.

However, the fitted quadratic model is nearly as difficult to justify as the linear model, since no criteria exist to rationalize it as a choice. According to Thomas, Finney, Weir and Giordano (2001), one should not consider a model unless there is some rationale for its plausibility. For the quadratic function to be the best model, its characteristics should be inherent in the data. In other words, the data should exhibit a minimum or maximum at an axis of symmetry (see Appendix 3.2, Section 3.2.3). There are simply no criteria or observations that could justify this for the source data themselves. Once graphed, it became evident that perceived individual problem severities in the sample tended to *decrease* over time. The quadratic model, however, suggests that they should increase after the minimum point had been reached on day 458 (see Figure 17, point TP). Observation of the mean perceived severity curve in Figure 17 certainly does not make such an increase evident. Consequently, rational argument would agree with the statistical testing above that neither the linear nor the quadratic models are the most appropriate, and that one of the others should be favoured.

On the basis of the statistical tests, the reciprocal model is better-fitting than the exponential model. However, both these models are very plausible: the first espouses an inverse proportion, while the second, a rate of decay proportional to the perceived severity (for further discussion, see Chapter 3, Sections 3.4.3 and 3.4.4). Additionally, their Residual SS values are close, being approximately 5.2 and 8.6 respectively. This study therefore examined these models more closely. First, the two fitted curves, together with the mean perceived severity curve, were plotted on the same system of axes (see Figure 20).

Figure 20: Composite: Exponential Decay and Reciprocal Functions, Fit to Mean Perceived Severity on System usage time. Sample: 204 Problem-factors over 40 user-systems.



As is evident from Figure 20, there is little divergence between the two fitted curves. The most, in fact, occurs on day 0, where the difference is just under 0.28 units. The fitted curves intersect three times at points A, B and C. Over the arc ABC, the maximum divergence between them is less than 0.05 units. In short, they are closer to one another than either is to the mean data curve. This study therefore concluded that there is no practical difference between the fit of these models. However, this does mean that they should be theoretically reconcilable; a proposition which was explored.

Both the exponential decay and reciprocal models suggest that the mean perceived severity should drop in the form of a concave curve. They merely differ very slightly in terms of the rate at which this happens. The rates of decline were determined as the first derivative of each fitted function, thus:

Reciprocal rate of decline:

$-126.752 \; / \; (\text{days} + 58)^2$ units per day

Exponential rate of decay:

$- 0.017177862 \; / \; e^{-0.01038 \text{ days}}$ units per day (e = Euler's Number, 2.7182818 . . .)

On day 0, these expressions reduce to 0.03768 and 0.01718 respectively, showing a higher rate of decline by the reciprocal model in the neighbourhood of zero. This is born out by Figure 20, as the reciprocal function starts at a greater vertical value and falls more steeply than the exponential decay function, crossing it at A. Thereafter the rates are very similar, since the curves very nearly coincide. In short, but for the first 26 days of the domain, there is little to choose between the two models in practical terms. The conclusion based on these models together, then, is that perceived problem severity is normally highest when first encountered on day 0. Probably because problems perceived to be most severe are ameliorated most quickly, the largest rate of decline in perceived severity tends to occur when the problem is seen to be at its worst. This supports the exponential model, which conjectures that the rate of decline is proportional to the perceived severity. This is usually on or close to its appearance, and this is normally on or close to day zero. However, it can also be argued that in the early phases, when the problem is probably at its worst felt, the user will be more motivated to find coping strategies or to have the problem otherwise addressed. This supports the reciprocal model, which posits that the perceived problem severity and time experienced are inversely proportional. However, as can be seen from Figure 20 as well as the preceding discussion, the models turn out to be similar in effect, at least for the 0-540 day domain.

A summary of key findings for the whole of Section 5.5 is given in Table 33.

Table 33: Summary of key findings: Section 5.5.

<u>Sample</u>: 204 problem-factors distributed over 40 USs.

Finding	Supported by	References
Source data		
When efforts were made to fit smooth functions to the data over the 0-730 day domain, only curves with unacceptably high Residual SS values could be produced. This was put down to the erratic behaviour of the data during US termination on Interval 5. This part of the study was thus limited to Intervals 1-4, covering a day 0-540 domain.	Trial and observation	Section 5.5 Figure 15
Linear Model		
Modest downward trend demonstrated.	Observation	Section 5.5.1 Figure 16
Not a very close fit.	Observation	Section 5.5.1 Figure 16 Section 5.5.6
Residual SS = 25.0792	Calculation	Section 5.5.1
Quadratic Model		
Residual SS = 15.4549, hence a better fit than the linear function.	Calculation and Observation	Section 5.5.2
Found to be a very much better fit than the linear function.	Test significant at $p << 0.0005$	Section 5.5.5 Table 32
Quadratic Model: Theoretical objection		
Despite the above, this model cannot be supported on theoretical grounds. It reaches a minimum and then starts to rise; something which the data do not do.	Mathematical theory and Observation	Section 5.5.6
Exponential Decay Model		
Residual SS = 8.6004, hence a better fit than the linear function.	Calculation and Observation	Section 5.5.4
Found to be a very much better fit than the quadratic function.	Test significant at $p << 0.0005$	Section 5.5.4 Table 32
Reciprocal Model		
Residual SS = 5.1808, hence a better fit than the linear function.	Calculation and Observation	Section 5.5.3
Found to be a very much better fit than the exponential decay function.	Test significant at $p << 0.0005$	Section 5.5.3 Table 32
Further consideration of the last two models		
The Exponential Decay and Reciprocal Models were found to be extremely close in practice, offering similar descending concave curves and only slight differences in the rate of descent over the 0-540 day domain.	Observation and Calculation of first derivatives	Section 5.5.6

5.6 Summary of Chapter 5: Results

The key results for the present study are given in this summary of Chapter 5 and, in summarized form, in Table 34.

5.6.1 The change in user satisfaction over the period of system usage

Section 5.2.5 discusses results relating to the behaviour of mean user satisfaction (mean-S) for USs over the period of system usage. It was found that during the life of a US, user satisfaction generally rises with time as the user gains experience with the system. For further detail, see Section 5.2.5 and Tables 25(a) and 25(b).

5.6.2 The overall relationship between user satisfaction and the cognitive gap

In Section 5.3, the results of the investigation of the absolute cognitive gap / overall user satisfaction nexus are reported. There it is noted that the absolute cognitive gap is negatively associated with overall user satisfaction measured as the *Mean S*, *Median S* and *Maximum S* for each member of the population of USs. The results, though statistically significant, were found not to be particularly strong. For further detail, see Section 5.3 and Table 28.

5.6.3 The relevancy of the cognitive gap at various points in time during system usage

Section 5.4 reports results associated with the relevancy of the absolute cognitive gap over the period of system usage. It is recorded there that the absolute cognitive gap is at least weakly negatively associated with user satisfaction over most of the two-year time domain, but is particularly strong in the regions of 85 and 652 days. It is suggested that somewhere in the neighbourhood of these days, systems may stall or terminate if the cognitive gap is high. See Section 5.4, Figure 11 and Table 30 for further details.

5.6.4 The asymmetric effects of the cognitive gap on user satisfaction

Section 5.4 also reports that the *signed* cognitive gap is positively associated with user satisfaction in the regions of 85 and 652 days. This suggests an asymmetric effect of the cognitive gap, and suggests that innovative analysts are more associated with user dissatisfaction than are adaptive analysts in these regions. For the associated graph, see Figure 12. For a summary of associated findings, see Table 30.

The asymmetric nature of the cognitive gap was also demonstrated by the behaviour of the analyst's KAI score over the time domain. It was found that during the first four months and last six of system usage, the analyst's KAI was negatively associated with user satisfaction, suggesting that the more innovative the analyst, the more dissatisfied a user of *either* cognitive style is likely to be, especially in the neighbourhoods of 85 and 652 days. This further suggests that adaptive analysts are better agents for change during the early stages of system usage than are innovative analysts. See Section 5.4, Figure 14 and Table 30 for further detail.

5.6.5 Changes in user perceptions of the severities of individual problems with time

In Section 5.5.4, the results are recorded for the enquiry into which of four possible mathematical models fits the change in a user's perceived severity of individual system problems with time. Of the options tested, the Exponential Decay and Reciprocal Models were found to fit the mean change in perceived severity the best. They offer similar descending concave curves and only slight differences in the rate of descent over a reduced domain of 0-540 days. For practical purposes, both models are evidently equally satisfactory. For details, see Section 5.5.6, Table 33 and Figure 20.

Table 34: Summary of key findings: the entire study.

Finding	Reference
<u>How user satisfaction changes with time</u>	
Finding	**Reference**
During the life of a US, user satisfaction will generally rise with time as the user gains experience with the system.	Section 5.2.5, Tables 25(a) and 25(b). Section 5.6.1.
<u>The overall relationship between user satisfaction and the cognitive gap</u>	
Finding	**Reference**
The absolute cognitive gap is negatively associated with overall user satisfaction measured as the *Mean S, Median S* and *Maximum S* for the population of USs. The results, though statistically significant, are not particularly strong.	Section 5.3, Table 28. Section 5.6.2.
<u>The relevancy of the cognitive gap over the period of system usage</u>	
Finding	**Reference**
The absolute cognitive gap is at least weakly associated with user satisfaction over most of the two-year time domain, but is particularly strong in the regions of 85 and 652 days. It is suggested that somewhere in the neighbourhood of these days, systems may stall or terminate if the cognitive gap is high.	Section 5.4. Section 5.6.3. Figure 11. Table 30.
<u>The asymmetric effects of the cognitive gap on user satisfaction</u>	
Finding	**Reference**
The signed cognitive gap is positively associated with user satisfaction in the regions of 85 and 652 days. This suggests an asymmetric effect of the cognitive gap, since innovative analysts are more associated with user dissatisfaction than are adaptive analysts.	Section 5.4. Section 5.6.3. Figure 12. Table 33.
It was found that during the first four months and last six of system usage the analyst's KAI was negatively associated with user satisfaction, suggesting that the more innovative the analyst, the more dissatisfied a user of *either* cognitive style is likely to be.	Section 5.4. Section 5.6.3. Figure 14. Table 33.
The above further suggests that adaptive analysts are better agents for change during the first three to four months of system usage than are innovative analysts.	Section 5.4. Section 5.6.3. Figure 14. Table 33.
<u>Changes in user perceptions of the severities of individual problems with time</u>	
Finding	**Reference**
The Exponential Decay and Reciprocal Models were found to fit the change in perceived severity of individual system problems. Better than either the linear or quadratic models. They offer similar descending concave curves and only slight differences in the rate of descent over the 0-540 day domain. For practical purposes, both models would be equally satisfactory.	Section 5.5.4. Table 33. Figure 20. Section 5.5.6

Chapter 6

Discussion and Conclusion

6.1 Introduction

This chapter initially sets out to summarise the contribution to knowledge made by the present study (see Section 6.2). The results of Chapter 5 are given in brief and these are followed by the immediate consequent conclusions. In summary, the results are as follows:

- The change in user satisfaction over the period of system usage was found to rise;
- The overall relationship between user satisfaction and the cognitive gap tested significant but weak;
- the cognitive gap was found to be weakly significant over the entire usage time, but particularly strong in the neighbourhoods of 85 and 652 days;
- The cognitive gap was shown to have an asymmetric impact on user satisfaction, innovative analysts being more associated with user dissatisfaction than their antipodes; and
- User perceptions of the severities of individual problems were found to decrease with time, the reciprocal and exponential decay models providing the best fit to the data (see Section 6.2).

Section 6.2.4 suggests new rules for system development based on the above so as to promote greater user satisfaction during system usage (For a note on the relationship between system usage and development, see Chapter 1, Section 1.1.1).

Next, Section 6.3 describes conclusions concerning the application of Herzberg's two-factor theory to system usage and development. It puts forth a proposed new model (the "mechanical" model) which describes motivation as a parallel to a driving force, and estimable resistance and inestimable resistance as parallels to the respective physical entities of net force, inertia and friction (see Section 6.3.1). In Section 6.3.2, empirical evidence is given for this model when applied to system usage. However, to show its relevance or otherwise in the case of system development, further research is required. Implications for IS practice are discussed in Section 6.3.3. Significant among these is the establishment of the new rules for system development, enumerated in Sections 6.2.4 and further discussed in Section 6.3.3.3.

Two further achievements of this study are outlined in Section 6.4: the construction and validation of the System Satisfaction Schedule (SSS) instrument, and the continued successful use of Kirton's Adaption-Innovation Theory together with the Kirton Adapion-innovation Inventory (KAI) in IS. An implication of this for IS practice is that Huber's (1983) conclusion that cognitive style theory contributes little to MIS or DSS development does not necessarily apply to the whole period of system usage, especially in the neighbourhoods of 85 and 652 days.

Section 6.5 suggests areas for further research. In summary, these are as follows:

- Replication of the present study as it stands (see Section 6.5.1);
- Further investigation of the rectilinear time-series model; (see Section 6.5.2);
- Validation of the impacts of the analyst/user cognitive gap generally over system usage life, and specifically in the two critical regions in the neighbourhoods of days 85 and 652 (see Section 6.5.3);
- Further validation of the SSS (see Section 6.5.4);
- Generalisation of this study's results to system development teams which are larger than the one user, one analyst cases investigated in this study (see Section 6.5.5);
- Further investigation of the proposed new "mechanical" model (see Section 6.5.6);
- Further investigation into the trends of perceived problem severities (see Section 6.5.7); and
- The contribution of user satisfaction to system success (see Section 6.5.8).

Finally Section 6.6 gives a summary of Chapter 6.

6.2 Contribution to knowledge

The common two-year time-scale on which all the S-data were plotted was only outlasted by 6 of the originally selected 62 user-systems (USs). This not only infers that most USs do not outlast a two-year period, but also that the present study collected its data over a significant period of US lives *in general*. As a US represents the major view a user has of a given system, the results give an overall idea of how users generally perceive their systems over time: a significant new insight. The contributions of the key results for the present study, described in Chapter 5 and Table 34, are discussed in this section.

6.2.1 The change in user satisfaction over the period of system usage

As discussed in Chapter 5, Section 5.2.5 the behaviour of mean user satisfaction (mean S) for USs over the period of system usage was found generally to rise over the period of system usage (see Chapter 5, Section 5.2.5 and Tables 25(a) and 25(b)). However, the sample trend was found to contain significant irregular variation in the first four and last three months of the two-year time domain. The corresponding hypothesis $\mathbf{H_{1(a)}}$**:**

During the life of the US, user satisfaction will generally rise with time as the user gains experience with the system;

was supported (see Chapter 5, Section 5.2.5).

It is not hard to speculate on why these results were obtained. As the early period of the US life unfolds, further expectations and disconfirmations may occur. The first period of system usage thus exhibits a somewhat irregular variation for S.

The explanation revolves upon the fact, as discussed in Appendix 3.1, Section 3.1.4, that the mean is affected by extreme values. Hence irregular variation in the mean S implies more irregular and extreme variation in the component values of S: that is, those for the individual USs. Some of the variation can also be explained in terms of the continued addition of systems up to day 180 of the domain (see Chapter 5, Figure 6). In other words, USs which contributed data later than day 0, may have imparted extreme values as they joined the survey.

Over Intervals 2, 3 and 4 the mean S, as suggested by the preceding discussion, becomes increasingly closer to the upward trend line, only exhibiting significant irregular variation again during Interval 5, as the USs start to terminate. The conclusion, then, is that during the first and last six months of US life, the value of S will tend to exhibit significant irregular variation, but on the whole over the entire domain, it tends towards an upward linear ascent.

6.2.2 The overall relationship between user satisfaction and the cognitive gap

In Chapter 5, Section 5.3, it is noted that the absolute cognitive gap was negatively associated with overall user satisfaction measured as the *Mean S*, *Median S*, and *Maximum S* for each member of the population of USs. The results, though statistically significant, were found not to be particularly strong (see Chapter 5, Section 5.3 and Table 28). The most significant correlation, for example, turned out to be -0.2041, yielding a maximum discordance of only some 60%, despite its statistical significance. This was put forth as a partial explanation as to why prior scholarly studies had found little evidence to support the use of cognitive style in IS research or practice (see Chapter 5, Section 5.3). It was also suggested that hypotheses $H_{2(a)}$ to $H_{2(d)}$ might posit models of the impact of cognitive style which are too simplistic to be very useful; a possibility supported by the analysis attendant to the third research question. In terms of theoretical development, this study sought to explain two effects:

1) Why the cognitive gap impacts user satisfaction at all; and
2) Why the effect is statistically significant, but weak.

Speculation as to why the cognitive gap impacts user satisfaction is obvious in terms of the Adaption-Innovation Theory described in Chapters 2, Section 2.2.4, and 3, Sections 3.3.2.1 and 3.3.2.2. The greater the cognitive gap, the greater the dissonance expected between the analyst and user (Kirton, 1976). The greater the dissonance, the more user complaint would be expected, and hence by the nature of the SSS instrument design (see Chapter 4, Sections 4.3.6 and 4.3.7), the lower the value of S. Thus far, the second set of results corroborated the prior theoretical development.

What also requires exploration, however, is the general weakness of the results for the impact of the cognitive differential. Only two explanations for this could be found. First, that the cognitive differential is but one of several factors impacting user satisfaction. Second, that the attendant hypotheses posit too simplistic a model: that in fact, the impact of the cognitive differential on user satisfaction may itself vary over the time domain. If it were strong on certain small regions of the domain and weak over others, an averagely weak effect overall could be expected. The first of these conjectures is not only feasible, it is also probable. If one considers all the imponderables associated with human attitude and ergonomic comfort, cognitive style is but one possible factor. Other factors could be any of the many improperly addressed hygiene factors not associated with system usage, proposed by Herzberg (see Appendix 2.7). Inadequate salary and managerial autocracy, having nothing necessarily to do with a system a user is trying to use, are examples of this. The second conjecture was explored by the testing of those hypotheses related to Research Question 3 (see below). At this stage, suffice it to say that the second conjecture was supported empirically in general terms, and quite extreme changes in the impact of the cognitive differential were observed. Overall, however, the effect was observed to be averagely weak.

6.2.3 The relevancy of the cognitive gap at various points in time during system usage and the asymmetry of its effect

In Chapter 5, Section 5.4, it is recorded that the absolute cognitive gap was found to be at least weakly negatively associated with user satisfaction over most of the two-year time domain, but is particularly strong in the regions of 85 and 652 days. It is suggested that somewhere in the neighbourhood of these days, systems may stall or terminate if the cognitive gap is high (See Chapter 5, Section 5.4, Figure 11 and Table 30). The principal hypothesis tested to support this question was, $\mathbf{H_{3(a)}}$:

The absolute cognitive gap, taken as | Analyst's KAI – User's KAI | is negatively associated with the S-Score during the US's life.

This was found to be supported or weakly supported over most of the two-year time domain, but particularly strongly in the neighbourhoods of 85 and 652 days (see Chapter 5, Section 5.4.1). It was thus concluded that in general, users are more satisfied (and hence complain less) over most of the time they interact with a system, if the system was developed by someone of similar cognitive style. This effect is, however, modest except in the critical regions comprising the neighbourhoods of 85 and 652 days, where it is particularly strong.

By comparison, the signed cognitive gap only tested significant in the neighbourhoods of 85 and 652 days. This suggests that the dissatisfaction in these regions is asymmetric, with analysts who are more innovative than their users being associated with higher user dissatisfaction, than the reverse. Elsewhere, however, the signed cognitive gap did not test significantly relevant at $p = 0.10$, power > 0.8 and so it was concluded that in general the absolute cognitive gap does not exhibit an asymmetric effect over most of the time domain (see Chapter 5, Section 5.4.2). The asymmetry was once again shown in the neighbourhoods of the same critical regions, where analysts' cognitive styles (as KAI-scores) were shown to be highly significantly associated with user dissatisfaction (see Chapter 5, Section 5.4.4). This suggests that innovative analysts in general are associated with higher dissatisfaction than adaptive analysts in these regions (see Chapter 5, Section 5.4.4).

It was noted that the relevance of the cognitive gap is highest at a point during the regions of irregular variation in the first four months of system usage and the last three. This invites the conjecture that the cognitive gap sets the basis for user complaint, which rises sharply during such periods of uncertainty in the US life. Turning first to the earlier phase, a study of Figure 11 of Chapter 5 suggests that user opinion actually starts quite positively, although insignificantly (point O) and takes some time to be consolidated (that is, some 85 days from the start of system usage) once some measure of expectation and disconfirmation has occurred. The attitude of the user tends thus to be disappointment. However, with perseverance, the user masters the basics of the system, reducing the need for analyst involvement and hence the effect of the cognitive gap. This explains why for the next period (up to the one-year mark at X) the cognitive gap not only is unsupported as relevant, but is actually rejected by the high power (0.80 to 0.96) of the 0.05 significance test. However, the misgivings of the user start to climb as (s)he becomes more experienced with the system and hence more au fait with its limitations. Notably, the cognitive gap now exhibits heightened relevance, as though the user confirms earlier suspicions that "defects" exist in the analyst's problem-solving strategy, and hence the system. This invites further conjecture that the user may initiate termination of the US, using these so-called "defects" as a reason. The user's attitude would be something like,

> "I knew all along that the system was no good, because it had an incompetent analyst. Now that I know the system better, my fears have been confirmed."

Such a process explains the behaviour as exhibited in Figure 11, for the section of the arc XY shows that the null hypothesis of independence is rejected at $p = 0.05$ and becomes highly significant over the region YQ before tailing off to point Z.

6.2.4 New rules for system development

The results discussed in Section 6.2.1 above show a continued mean linear rise in the late part of the time domain even when many of the USs are terminating. This suggests the conclusion that user satisfaction continues to increase with time. Hence, the first rule:

> ***To optimise user satisfaction employ strategies that will keep a user using the same system for as long as possible.***

There may, of course be other counterbalancing considerations, such as a necessary technical and/or system change, to avoid organisational stagnation.

As discussed in Section 6.2.2, a significant association between the absolute cognitive gap and the level of user dissatisfaction, implies that one can reduce user dissatisfaction by arranging for the analyst-user cognitive gap to be as low as possible. The most obvious observation emanating from the results summarised in Sections 6.2.2 and 6.2.3, is that users are more satisfied with systems over most of the time that they interact with them, if developed by persons of similar cognitive style. Hence the rule:

> ***Minimising the absolute analyst-user cognitive gap positively impacts user satisfaction. To optimise user satisfaction, the analyst should be chosen to have a similar cognitive style to the user.***

This rule is tractable to implement, since cognitive style can be easily and cheaply measured with the aid of the KAI (see Section 6.4.2). One should note the potential down side of this, however. If both analyst and user are of similar cognitive styles, the associated system may tend to reflect behaviours associated with that cognitive style. Hence for example, from a pair of adaptors, a system could emerge which is insufficiently innovative to maintain the organisation's competitive edge. Conversely, an innovative dyad may generate a system which fails because it is thought to depart too radically from what a wider body of users considers 'an accepted' way of doing things.

Another two rules stem from the asymmetric nature of the impact of the cognitive gap at the critical regions in the early and late lives of USs (neighbourhoods of 85 and 652 days respectively). This asymmetry manifests itself in two results, with slightly different implications and thus provides the bases for separate rules. In essence, this suggests that the simple rule of minimising the cognitive gap (see Section 6.2.2) effectively requires further refinement. First, analysts who are more innovative than their users are associated with higher dissatisfaction in these critical regions, than the reverse. Hence:

> ***In the critical regions in the early and late lives of system usage, an analyst with a more adaptive cognitive style than the user reduces user dissatisfaction. To optimise user satisfaction in the two critical regions early and late in system usage, (and also not overly to violate the last rule), the analyst should be selected to be <u>slightly</u> more adaptive than the user.***

This would apply even if both were high-scoring innovators. Second, the analyst's cognitive style as a KAI score was shown to be highly significantly associated with user dissatisfaction in these regions (see above). It was thus concluded that innovative analysts are not the successful agents for change that adaptive analysts are when ushering in a new system. This suggests the rule:

> ***Adaptive analysts are a better choice in the early life of a user's experience with a system than are innovative analysts, since, when it comes to the introduction of new systems, adaptors are evidemtly more successful agents for change.***

6.2.5 Changes in user perceptions of the severities of problems with time

The enquiry into which of four possible mathematical models fits the change in a user's perceived severity of individual system problems with time, is reported in Chapter 5, Section 5.5.4. Since the steady termination of USs created curve-fitting difficulties in the last six months of the time-domain, this part of the study was limited to its first 0-540 days only (see Chapter 5, Section 5.5). Four commonly used models were tested, these being the best-fitting linear, quadratic, reciprocal and exponential decay functions. The exponential decay and reciprocal models were found to fit the data best, and did not differ significantly from one another (see Chapter 5, Section 5.5.4 and Figure 20). It was thus concluded that the exponential decay and reciprocal models offer similar descending concave curves with only slight differences in the rate of descent over the 0-540 day domain (see Chapter 5, Section 5.5.6). For practical purposes, it was thus proposed that both models are nearly equally satisfactory (see Chapter 5, Section 5.5.6). The exponential decay model suggests that, but for scaling constants, the user's perceived severity of a problem is directly proportional to the instantaneous rate at which the perceived severity declines. The reciprocal model, on the other hand, suggests that, but for scaling constants, the length of time a user experiences a problem is inversely proportional to its perceived severity.

Speculation as to why the exponential decay and reciprocal models are the best-fitting is based on the types of phenomena which these models tend to describe. In the case of the exponential decay model (see Appendix 3.2, Section 3.2.4), the perceived problem severity is proportional to its rate of decline. Since problems thought to be most severe will probably be most quickly addressed, this model is not only reasonable but is consistent with observation (see Chapter 5, Section 5.5.4). The other model, which was found to fit marginally better, was the reciprocal model. Here the underlying assumption is that, but for scaling constants, the time for which a problem is experienced is inversely proportional to the severity of the problem (see Appendix 3.2, Section 3.2.5). As users may learn coping skills – ways of "getting round" problems – or of having them ameliorated or eliminated, this model seems as logically plausible as the last. The observation that they both fit the data well was thus not considered anomalous.

6.3 Proposed modifications to Herzberg's two-factor theory of motivation for information system usage and development

Herzberg (1966, 1968, 1987) suggested two classes of factors which contribute to job satisfaction: motivators and hygiene factors. He appears to have used the term *satisfaction* interchangeably with *motivation*, setting it at tacit odds with all the factors comprising factor-based (computer) user satisfaction instruments (see Chapter 3, Section 3.3.1). Authors such as DeLone et al. (1992) note that 'satisfaction' has a 'face validity', making it evident that the meaning of user satisfaction is not really clear to them. Other authors such as Cheney and Mann (1986) call for more empirical research into 'satisfaction factors'.

The present study showed that user satisfaction factors employed in an assortment of recent factor-based instruments are synonymous with Herzberg's hygiene factors (see Chapter 3, Section 3.3.1.2 and Table 13). From the point of view of the IS researcher, there is a practical objection to the use of the hygiene factor concept, since the presence of such a factor may only be demonstrable when its incomplete address invokes a complaint. This makes a complete set of hygiene factors in respect of the context in which a system's development or usage occurs, difficult to predict. Nonetheless, researchers such Bailey and Pearson (1983) call for the need for a *complete* set of such factors, to reliably measure user satisfaction (see Chapter 2, Section 2.3.1). It thus is more tractable and less artificial to identify and rate *dissatisfiers*, which are simply defined as the sources of complaints, as and when they occur. Dissatisfaction, then, is the cumulative weighted severities of the identified dissatisfiers, and satisfaction the lack of dissatisfaction. That this approach is valid was demonstrated empirically in the pilot studies described in Chapter 4, Sections 4.3.6 and 4.3.7.

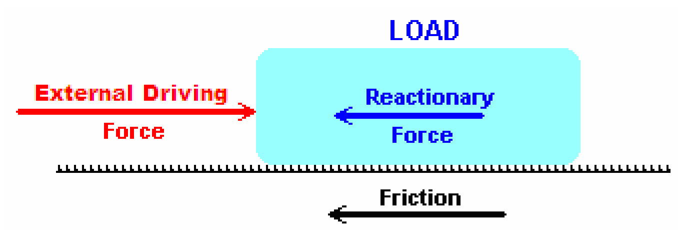
Compared with the hygiene factor alternative, this approach is decidedly more tractable in practical terms, as there is no obligation on the part of the researcher to identify a complete list of dissatisfying factors. All that is required is the noting of dissatisfaction as and when it occurs, as complaints prompted by dissatisfiers. The closeness of these dissatisfiers' weighted total to zero then yields a measure of overall satisfaction. In the calculation of S in the preceding chapters, the weighted sum of the dissatisfiers was subtracted from an arbitrary constant of 40. Apart from the fact that this gives satisfaction values which are normally positive, it otherwise has the same mathematical effect. The antipodes of the so-called satisfaction factors found in user satisfaction instruments (see Chapter 3, Table 13) give a summary of what typically may dissatisfy users. There is no guarantee, however, that this or any future list will ever be complete. In fact, factors may change with changes in technology, as noted by Doll and Torkzadeh (1988). Another advantage of the dissatisfier approach, therefore, is that it requires no updating with changes in technology. All one measures is a user's complaints about a system or its manner of implementation. If the user identifies a problem it is a sign of a dissatisfier in existence at that point in time, and its intensity measures the effect it may have in demotivating the user.

Herzberg's theory leaves the terms motivation and satisfaction incompletely differentiated, and no significant progress in differentiating the terms since, could be found in the IS literature. This means that scholars basing their work solely upon Herzberg's theory appear to rely on a 'face validity' of the term 'satisfaction'. In confirmation, Locke (1983) rejected the idea that there can be two mutually exclusive sets of factors which satisfy or dissatisfy (see Appendix 2.7). Also, Caston and Braito (1985) suggest that Herzberg's theory tries to explain job satisfaction, rather than work motivation, and in any case does not successfully measure job satisfaction (see Appendix 2.7). In other words, a complete list of hygiene factors applying to any work situation, mutually exclusive with motivators, usually cannot be produced.

6.3.1 The basis of the proposed motivational model

The present study suspected that a failure rigorously to define the terms 'motivation' as distinct from 'satisfaction' and 'dissatisfaction' could be at the heart of these criticisms. To increase the rigour of the associated concepts, an analogy was borrowed from the physical sciences as the basis of a model. This was that of a particularly simple machine consisting of a massive load being pushed across a rough, horizontal plane by a driving force. The driving force is resisted by the inertial reactionary force of the load as well as the friction between the load and the rough plane (see Figure 21).

Figure 21: A Simple Machine used as an analogy by the proposed Mechanical Motivational Model.

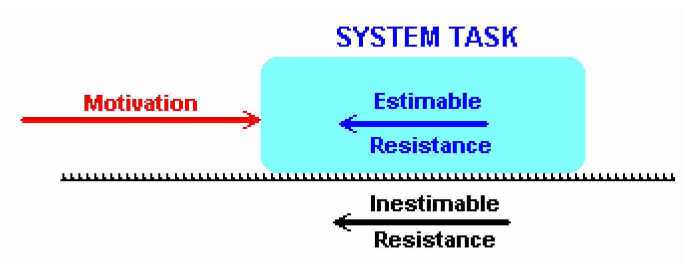


The laws of mechanics underlying this simple case of a machine (and, in fact, all other machines) are given in Appendix 6.1. In summary, these are:

1) A motivating net force is opposed in two ways; by the inertia of masses and by other forms of resistance, such as friction. Inertia responds to a motivating force by an equal but opposite reactionary force. The body responds to a net force in a predictable way, accelerating as described by Newton's Second Law of Motion (see Appendix 6.1)
2) Friction responds to a net force by applying an equal and opposite force but only up to a certain maximum. If this maximum is less than the net driving force, the body accelerates in the direction of the driving force. If the frictional maximum is greater than the net driving force, the body remains at rest or decelerates. If the net driving force balances the frictional maximum, the body will either remain at rest or continue with a constant, rectilinear velocity.
3) The previous two factors dictate that it requires more energy, applied by way of net driving forces, to start a machine in operation than to keep it running.
4) Some associated friction is always present, so no machine will run perpetually without a continued energy input, even if it does no work on the external environment.

An effort to treat information systems as machines, just as one might do with living organisms, is complicated by the fact that they contain human elements, with all the imponderables of human behaviour. Hence, although a case can be made that an information system is a machine in the physical sense, this is *not* the approach intended here. Rather, the very simple *standard machine* represented in Figure 21 is to be used metaphorically, as a source of parallels and analogies, so as to shed light on the motivating and retarding processes associated with system usage and development. The standard machine of Figure 21 has elements *paralleled by* the proposed *mechanical model* for the motivation to use or develop an information system, represented in Figure 22.

Figure 22: Proposed Mechanical Model for the Motivation to use or develop an Information System.



A comparison of the two diagrams will make it clear which entities in the proposed mechanical model and standard machine are treated as analogies. While the objective of the standard machine is to move the load across a rough plane, the metaphoric equivalent in the mechanical model is to carry out some system task, such as system utilisation, development or maintenance.

Where the simple standard machine is driven by a *driving force*, the mechanical model is propelled by some form of *motivation*, which itself may be composed of several *motivators*. Motivators are factors which actively motivate system usage or development, and equate to Herzberg-type motivators (see Appendix 2.7).

In the standard machine, the driving force is opposed by an expected *reactionary force* associated with the load's *inertia*. It is also resisted by the less estimable phenomenon of *friction* (see Appendix 6.1). The precise behaviour of a load of known mass, in response to a known net force can be accurately determined. In contrast, quantitative forecasts of friction are not so easily made. Usually, friction can only be measured by experiment.

The corresponding analogies in the mechanical model are *estimable resistance*, and *inestimable resistance*. Estimable resistance consists of those resource requirements which are the *expected overheads* of the system usage, development or maintenance task. They usually can be forecast, at least approximately, and should be accounted for in project plans, budgets and schedules. *Inestimable resistance* cannot be estimated in advance, and usually only makes itself known when team members start complaining. The labour of resource usage and management requires human effort, and where this causes sufficient stress, complaints may also be elicited. Hence, when overall resistance is to be measured, both estimable and inestimable resistance can be detected by virtue of complaints.

Examples of estimable resistance factors attracting complaints would be the lack of resources, knowledge and/or experience that the user feels (s)he needs, to use the system more efficiently and effectively. Known resource deficiencies are generally expected to be rectified in due course. However, until then their absence may retard the system task and will probably elicit complaints from team members. Estimable resistance may be the result of missing or inadequate funding, hardware, packages, user training, and so on. For example, given a new system installation, user training is likely to have been scheduled and budgeted for. However, until the user has had the necessary training to use the new system effectively, user dissatisfaction in this respect will prevail.

As discussed above, friction is paralleled by *inestimable resistance* in the mechanical model. An example of inestimable resistance is exemplified by the following scenario:

After the introduction of a new payroll system, it is found that the deductions are wrongly calculated for two out of 200 employees in an organisation. The IS staff cannot rectify the error, so the pay clerk has to do the associated calculations by hand every pay day. This gives him extra work and means that some people don't get paid before the end of the working day. There are a number of reasons why this is inestimable resistance. First, it was not foreseen before the system was implemented. Second, its discovery cost time (and doubtless irritation). Third, it slows down the payroll process every pay day. Fourth, the human responses of the pay clerk and the employees, who all see the issue as a permanent, ongoing nuisance, are unpredictable. Some people may exhibit patience, while others may make various demands or exhibit more overt responses. Most seriously, the motivation to use the payroll system is reduced. Resistance like this can be expected, but neither the type of such faults nor their impact can be estimated in advance.

In the standard machine, friction will always be present. However, it can be reduced to a minimum by smoothing the contact surfaces and lubricating them. The *optimum* machine, requiring the *minimum* motivational force, will be one where friction is reduced to the minimum, but cannot be reduced to zero. In the mechanical model, the parallel, *inestimable resistance*, can be minimised with maintenance and/or learnt coping strategies, but cannot be reduced to zero (this is justified empirically below: see Section 6.3.2). *Complete satisfaction* in the mechanical model implies *zero resistance* of both types, which it is submitted, like zero friction and zero inertia for a real load, is an impossible condition.

As Herzberg established the link between high motivation and few complaints, and low motivation and high complaints (see Section 2.7), Mullany (1989) was able to establish his R-Score, a user resistance measure, by summing respondents' weighted complaints of (see Chapter 2, Section 2.3.3). This enabled the development of the SSS and S-statistic, the satisfaction measure used in this study (see Chapter 4, Sections 4.2.6, 4.2.7 and 4.2.8). But for the one CVS scale, valid S-Scores imply a definition of *user satisfaction* as a measure of the closeness of the total weighted resistance to zero. Support for this claim is given in Section 6.3.2 below. In short, this study assumed that where a user complaint occurs:

- It signifies the presence of a user dissatisfier, which in turn implies a probable reason for task retardation;
- The nature of the complaint will indicate whether the cause is a missing resource (an estimable overhead) or an issue not predictable in advance (inestimable resistance); and
- The weighted intensity of a complaint in either category is a satisfactory measure of the perceived severity of the corresponding dissatisfier.

6.3.2 Empirical verification of the mechanical model for system usage

The proposed mechanical model, like its physical counterpart, should be experimentally verifiable if all its intrinsic analogies hold true. Validations were found by revisiting certain of the results given in Chapter 5. For instance, in the simple machine (Figure 21), if there is a net force on the load it will accelerate at a constant rate (see Appendix 21). Similarly, in the proposed mechanical model, as experience is gained, user satisfaction should improve at a constant rate, yielding a linear trend with a positive slope (see Appendix 3.2, Section 3.2.2). This was shown to be true for the research sample, at least for the mean S trend, and hence inferred for the population of USs (see Chapter 5, Section 5.2.5 and Figure 9). Further, if as the mechanical model claims, inestimable resistance cannot be totally eliminated, one would expect that the mean perceived problem severity of a representative sample of complaints would reach a minimum greater than zero (see above). This was also found to be the case (see Section 6.2.5). The two best-fitting curves to the mean perceived severity data, exhibit approaches from above to positive, limiting minima (asymptotes) (see Chapter 5, Sections 5.5.3, 5.5.4 and 5.5.5). This finding further supports this aspect of the mechanical model for system usage.

As discussed above, satisfaction is defined by the proposed machine model as the lack of dissatisfaction, affording reduced resistance to the motivational drive. This is supported empirically by two of the pilot studies described in Chapter 4. In Section 4.3.7, for example, it was found that users' expressions of satisfaction and dissatisfaction are not strongly negatively associated, suggesting that the former is really an indeterminable mix of motivation and satisfaction. Additionally, the S-Score (without individual positive ratings) showed greater construct validity than did Baroudi, Olson and Ives's (1988) User Information Satisfaction short-form (the UIS) (see Chapter 4, Section 4.3.7). Notwithstanding, the literature survey which underpins this study, found that the UIS remains a user satisfaction standard, much used by IS researchers, to the present (see Chapter 2, Section 2.3.1).

A comparative summary of Herzberg's two-factor theory of motivation and the proposed machine model are given in Tables 35(a) and 35(b) respectively.

Table 35(a): Motivators And Hygiene Factors, According To Herzberg's Two-factor Theory of Motivation

MOTIVATORS	HYGIENE FACTORS
Achievement in the job Recognition of good work Challenging work	No company bureaucracy No stringent supervision Adequate salary
Responsibility for one's own job Advancement opportunities Growth skills	Good relations with co-workers Good working conditions Adequate job security
Satisfaction depends on the strength of such factors. They are mutually exclusive with hygiene factors.	*Dissatisfaction increases when factors such as these are missing or inadequately addressed. There is no way of guaranteeing a complete list of these for the context in which any particular system usage or development occurs.*

Table 35(b): Motivators and Dissatisfiers, According to the proposed Mechanical Model suggested in this chapter

MOTIVATORS	RESISTANCE FACTORS
Achievement in the job Recognition of good work Challenging work	Inadequate experience of system (estimable*) Inadequate IT hardware (estimable*) Inadequate computer literacy (estimable*)
Responsibility for one's own job Advancement opportunities Growth skills	Bureaucracy of department (inestimable*) Stringent supervision (inestimable*) Poor working conditions (inestimable*)
Motivators provide expectations of positive and negative outcomes. They thus stimulate IS development and use to realise positive outcomes and/or to avoid negative outcomes. They provide a motivating force which is resisted by both estimable and inestimable resistance factors.	*Satisfaction depends on factors such as these being few and low in intensity, so that the expectations of positive outcomes are not thwarted. This list can never be guaranteed complete, but dissatisfaction, as measured by individuals' weighted complaints, is an indicator of the type and severity of the associated resistance factor.* * usually

6.3.3 Implications for practice

While scholarly research aims at the identification of patterns and principles, most management studies, including IS, have applied spin-offs important to the practitioner. This section therefore aims to offer implications of the present study for IS practice.

6.3.3.1 US life

As the present study found that fewer than 26% of USs outlast a period of 18 months to two years (see Section 6.2.1), practitioners may choose this time span as a "safe" forecast period of system usage by the same person. This particularly in the light of the speculation (see Section 6.2.1) that the number of USs surviving two years is likely to be less than 10% rather than 26% for the population. They should also note the upward tendency of S, meaning that long usage implies greater user satisfaction.

This provides further input to the question of whether a system should be redeveloped or replaced, since getting the system up to the two-year mark could be an economic option. On the other hand, a US which exhibits significant user dissatisfaction and has been used for 18 months or more is probably one that is about to terminate. This suggests that the associated system could be a good candidate for fast replacement or radical redevelopment if the user is the only, or at least the key stakeholder involved. The overall level of user satisfaction in the *organisation* might thus be increased more quickly.

6.3.3.2 Minimising the cognitive gap between user and systems analyst

In accordance with the results discussed in Section 6.2.2, the minimising of the cognitive gap as a means of improving overall user satisfaction is warranted, although the improvement could be weaker than expected. Despite this, it can do little harm to minimise the cognitive gap if this helps to create contented users and if the overheads of so doing are affordable. Unfortunately, there can be expensive overheads, such as the need to employ more IS staff; so that, for a given user, one has a larger spread of analysts to choose from. Judicious recruiting is thus indicated. Recruiting normally occurs when there is a *need* for more staff with certain *skills*. Hitherto cognitive style has played little role in this. If the cognitive styles of recruits were added to the list of organisational needs, recruiting could seek new IS analysts to match the distribution (either known or expected) of user cognitive styles (as KAI scores).

6.3.3.3 Application of the new rules for system development

In Section 6.2.4, new rules were identified as emanating from the results regarding the relationships between user satisfaction and the cognitive gap. For the benefit of this discussion, they are reproduced here, thus:

1. ***To optimise user satisfaction look for strategies that will keep a user using the same system for as long as possible.***
2. ***Minimising the absolute analyst-user cognitive gap <u>positively impacts</u> user satisfaction. To optimise user satisfaction, the analyst should be chosen to have a similar cognitive style to the user.***
3. ***In the critical regions in the early and late lives of system usage, an analyst with a more adaptive cognitive style than the user reduces user dissatisfaction. To optimise user satisfaction in the two critical regions early and late in system usage (around 85 and 652 days), the analyst should be selected to be slightly more adaptive than the user.***
4. ***Adaptive analysts are a better choice in the early life of a user's experience with a system than are innovative analysts, since the former are more successful agents for change.***

These rules have immediate application in practice. For example, if satisfied users are a priority, adaptive users provide a straight forward choice of analyst. The latter should be an adaptor (Rules 2 and 4), and preferably more adaptive than the user (Rule 3). In this scenario, *ceteris paribus*, the probability of long system usage (two years or more) by a generally satisfied user is high. The same choice thus provides a strategy as indicated by Rule 1. However, if one examines the results discussed in Chapter 5, Section 5.4.3, the impact of the user KAI on user satisfaction over time does not test strongly significant anywhere on the time domain. A further conclusion was thus drawn that no great consideration has hitherto been given to the cognitive styles of users in the choice of their analysts. This conclusion is hardly surprising, as few of the results discussed in this study were previously known.

The asymmetric nature of the cognitive gap's impact in the critical regions around 85 and 652 days does not make the innovative user scenario quite as easy to address. According to Rule 2, overall user satisfaction will be improved if the analyst is also an innovator. However, this may produce a highly dissonant start to the use of the system, since the asymmetric effect of the cognitive gap suggests that innovators are poorer agents for change than are adaptors. In fact, the cognitive gap impact may be so significant that usage may stall and not get underway. Rule 3 thus seems to be the rule of choice in this situation: to choose an innovator as the analyst, but to ensure that (s)he is *less innovative* (lower KAI score) than the user. As innovators tend not to wed themselves to systems for long (see Appendix 2.1), system usage by innovative users is likely to be shorter than for adaptive users, whatever strategy is employed.

A further issue for the practitioner is the high relevancy of the cognitive gap in the neighbourhoods of days 85 and 652. The first of these regions should be seen as a potential problem zone where an extreme cognitive gap could cause a new system development effort to flounder and stall. Every effort should be made to support system usage, the user and the analyst at this stage. This may even include individual and team counselling for both the user and the analyst.

In the case of the later region in the neighbourhood of day 652, the relevancy of the cognitive gap, measured as $t_a = -0.6$ suggests that some 60% to 80% of users will blame analysts of unlike cognitive style in some way when the US is in a state of decline. The practitioner needs to decide on one of three courses of action. First, (s)he might consider the liaises-faire approach of doing nothing. This of itself costs nothing and can be a saving on the emotional energy of the practitioner and other management staff. It does have possible overheads, however. For instance, a floundering system in an organisational setting, which the user might well be helping to make fail, could cost customer goodwill. Disgruntled shop assistants, who publicly range themselves against what they see as "faulty" point-of-sale or delivery systems in front of customers, would be possible examples. A further overhead is the potential loss of good user employees if stressed by systems in their death throes. To return to the scenario given in Section 6.3.1, the payroll system which pays late, is but one of many examples. The pay clerk, who not only gets paid late himself but has to put up with everyone else's complaints, could be tempted to resign under the stress. In cases such as these, a second option might be to discontinue the old system more quickly than if left to its own devices. However, this may not be feasible if the IS and other resources are not immediately available to put an alternative in place. A third option might be to try and "fix" the problems in the old system as quickly and as unobtrusively as possible. Even if the resources were available to make this possible, however, it could lead to the preservation of an old-style system long after the real usefulness of the associated IT has ended. In other words, one might be putting off the inevitable rather than permanently solving the problem. Regrettably, this study defines the problem for the practitioner more than it offers solutions. However, at least it identifies and clarifies some counterbalancing issues when making the preliminary decision to replace a system, to redevelop it or to leave it unchanged.

6.3.3.4 The reduction of perceived individual problem severity with time

The results discussed in Section 6.2.5 show that in general, the perceived severity of individual system problems decrease with time, and that the decrease is best modelled as either a reciprocal or exponential decay curve. The practitioner should note that the shapes of these curves are usable under certain circumstances. The reciprocal model suggests, *inter alia*, that the longer a user experiences a problem the less severe it will appear to him/her. This is probably as a result of increased experience and familiarity with the problem, the development of coping strategies with it, and/or relief afforded by having encouraged the analyst to fix the problem. Both models suggest that most problems tend to linger indefinitely in some form, as the curves approach horizontal asymptotes greater than zero (see Chapter 5, Figures 18, 19 and 20). With their relatively high initial values (see the same), both models also suggest that the *worst* perceived problems in new systems should have the *highest* priorities of address.

6.4 Other achievements of this study

6.4.1 The development and validation of the SSS instrument and S-statistic

In addition to the new rules for system development outlined in Section 6.2.4 and the proposed modification of Herzberg's two-factor theory for system usage and development (see Section 6.3, Figure 22 and Tables 35(a) and 35(b)), the present study has developed an evidently valid and reliable instrument, namely the System Satisfaction Schedule (SSS) (see Chapter 4, Sections 4.3.5 to 4.3.8). Two additional advantages which this instrument has over all prior user satisfaction measures found, is that:

- It does not require updating with the inevitable changes in technology; and
- It can be used for repeated measures of user satisfaction. It thus provides a means of reliably obtaining a users' satisfaction with the same system repeatedly over time, and hence enables time-series-type studies of user satisfaction to be conducted.

6.4.2 The successful application of cognitive theory in the field of information systems

The present study demonstrates that the successful use of Kirton's (1976) Adaption-Innovation Theory and Kirton's Adaption-innovation Inventory (KAI) instrument (see Chapter 5, Sections 5.3 and 5.4) is a viable means of measuring cognitive style in Information Systems research and practice. The administration of this instrument by a properly certificated practitioner is inexpensive and takes only a few minutes of the respondent's time to complete (Kirton, 1999). It thus provides an economically attractive option for organisations to determine the cognitive styles (as KAI scores) of their employees, so making it viable to use these in IS staff recruiting and IS team selection (see Section 6.3.3.2 above).

With the aid of the SSS and Kirton's (1976) KAI, this study has demonstrated that the analyst-user cognitive differential indeed does have high impacts over quite specific periods in the early and late life of system usage. This supports the findings of Mullany (1989) that the cognitive gap is positively associated with user resistance. However, it does not rule out the potential importance of other factors. It shows that views such as those of Huber (1983) (that cognitive style will probably never add anything significant to IS development) do not apply over the whole period of system usage. Thus it vindicates the suggestion by Carey (1991), that cognitive style should not be abandoned in IS research; although her literature survey did not discredit Huber's (1983) position.

6.5 Limitations of this study and suggested areas for further research

The limitations of this study are considered next, together with areas for further research which they suggest. Implications for research have been noted throughout the chapter with discussion of each of the results. This section thus essays to produce a summary of these together with some future research possibilities, and their direction.

6.5.1 Replication of the present study

This study is evidently the only one of its kind in existence at the present time, which has attempted to measure and describe changing user attitudes continuously over a time-domain as long as two years. As it so happened, this turned out to encompass the period of usage of all but six of the 62 associated sample user-systems, suggesting that the two-year time domain indeed is a substantial period in system usage generally. However, this study is a first step and should be viewed with the indulgence of a first step. It was in part exploratory, owing to the lack of scholarly precedents for many of its time-based hypotheses and methods. To gain wider acceptance it needs replication, verification and doubtlessly, eventual modification.

6.5.2 Verification or rejection of the rectilinear time-series model for overall user satisfaction

A specific suggestion for further research is a revisit of the time-series model for overall user satisfaction. This result either proposes a new law of user satisfaction, or an opportunity for researchers to replicate the results and possibly find a more accurate law of user satisfaction. The proposed law is:

On the average, user satisfaction increases linearly over system usage time.

In accordance with the scientific method, this “law” is the result of observation, conjecture, hypothesis formulation and hypothesis testing. The present study could not find a better trend line than a straight line with a positive slope. More accurately constructed research with a larger sample and directed specifically at this area may well lead to a better-fitting trend line.

6.5.3 Validation of the general and specific impacts of the analyst-user cognitive gap

An obvious area for further study is user satisfaction in the neighbourhoods of days 85 and 652, where this study found the cognitive gap to be most relevant. The precise points in time, of course, need plenty of further investigation and verification. It is expected that further research will reveal a distribution of times in the vicinity of these values where the cognitive gap is likely to reach its most relevant values in any system evolution. Armed with this, both research and practice could explore the margins of error and set confidence intervals for these points, thus providing accurate estimates of approximately where a new system development effort may stall, and approximately when one might expect an old system to flounder and terminate.

In terms of the impact of the analyst-user cognitive gap, future studies could achieve results quite rapidly by collecting data from several user-systems, defined as in Chapter 3, Section 3.2, but which exhibit a variety of ages up to or exceeding the two-year time domain used here. With more such research a better idea of how user satisfaction changes over time would emerge. More investigation in the first time region where this study found the cognitive gap to be particularly relevant, could be carried out by studying new samples of USs that are in their first 120 days of usage. Similar studies could be carried out for USs whose lives are in a similar neighbourhood of 652 days.

In both Sections 6.2.2 and 6.2.3 it was noted that generally the cognitive gap is weak over most of the time of system usage. The implication for further research is that any survey which randomly measures user satisfaction and the cognitive differential as a once-off should expect weak results, even if they are statistically significant.

More significant results are likely to be achieved by using approaches similar to those suggested above.

6.5.4 Further validation of the system satisfaction schedule (SSS)

As this is the only significant study which has made use of the SSS, the SSS itself requires further verification and validation before it can achieve wider acceptance as a standard research tool. Such studies could either replicate the verification tests described in Chapter 4, Sections 4.2.6 and 4.2.7, or could test the SSS against other criteria and instruments as they emerge from the literature.

6.5.5 Verification of implications for larger system development teams than one user and one analyst

As IS development teams may consist of more than just the one analyst and one user considered here, studies need to be devised which can identify optimum cognitive mixes in larger groups. Some of the criteria identified in the present study and expressed as new rules for system team choice (see Sections 6.2.4 and 6.3) could well apply to such teams. One might conjecture, for example, that a team of analysts embarking on a new system development for a given user should contain adaptors as the best agents for change, members who match the user’s cognitive style generally to reduce dissonance and some with intermediate KAI scores to act as bridging agents (Kirton, 1999, 2003). However, such recommendations remain conjectures only until further research has been carried out with IS teams in excess of two.

6.5.6 Validation, modification and/or extension of the proposed machine model

The only validation of the machine model proposed in Sections 6.3.1 and 6.3.2 was one set of results which supports system usage aspects only. It needs further research to demonstrate that the model holds (or does not hold) when applied to system development. As with any other new model, its general acceptance will require several more studies. These could include literature surveys, where attempts are made to align existing research with the model. Empirical studies replicating the verification described in Section 6.3.2, are also to be encouraged.

A possible extension of the use of the machine model is into other technologies which, like computer systems, are intended for human use. If the machine model applies to computer-based systems, then it should also apply, for example, to the plethora of electronic equipment found throughout the industrial, commercial and domestic worlds of today. For example, the possibility of using the SSS to find out how consumer satisfaction with new appliances changes over a period of time after purchase, invites investigation. Consequent answers could assist manufacturers in future designs, especially over issues of complexity, appearance, convenience and so on. Both product development and marketing efforts could potentially benefit.

6.5.7 Further investigation into the trends of perceived problem severities

Future research could investigate yet further the way that the perceived severities of system problems decline over time. Owing to instability caused by the steady termination of USs during the last three months of the two-year term in this study, the domain had to be restricted to 0-540 days for the curve-fitting procedure (see Chapter 5, Section 5.5). This may have resulted in a wrong choice of the best-fitting curve. Additionally, if one refers to Figure 20 in Chapter 5 it is evident that while the reciprocal and exponential decay models are close to one another, neither is as close to the actual mean data curve. This provides scope for the development of other models based on future data, which may more accurately reflect the overall trend in perceived problem severity. With a much larger sample of USs, it should be possible to select a final sample in which all the USs outlast two years, thus providing a greater domain over which to fit curves. Various other models (see Hyams, 2003), might then become evident as better options than the reciprocal and exponential decay models found to be the best in this study (see Chapter 5, Section 5.5).

As discussed in Secion 6.3.3.4, practitioners are encouraged to address the worst system problems first. However, from this study, the only guide would be which problem the user *thinks* is worst. As it is questionable whether the problem which is *thought* to be worst, is best prioritised for early attention, future research is encouraged to establish a better definition of severity than individual and evidential user opinion. The opinions of a number of system users, managers and/or other organisational observers might serve this purpose. A study comparing the two points of view might not only be academically interesting but also provide more precise options when prioritising the addressing of individual system problems.

6.5.8 The contribution of user satisfaction to system success

As discussed in Chapter 2, Section 2.3.3, several studies claim a link between user satisfaction and information system success (see Table 8). However, DeLone and McLean produced two models of system success (1992, and in modified form in 2003) in which they incorporated 'user satisfaction' as a construct of system success, but not synonymous with it (see Chapter 2, Section 2.3 and Figures 1 and 2). They favoured the Bailey-Pearson (1983) instrument as one of the best for supplying a measure of this construct. Now that the SSS is available, however, an alternative way of measuring user satisfaction has entered the arena. An attribute of the SSS not hitherto focused upon is that it records users' complaints. These could, in a future study, be matched with the some of the constructs of the D & M models, such as:

- System Quality;
- Information Quality;
- System Use;
- User Satisfaction;
- Individual Impacts; and
- Organizational Impacts (see Chapter 2, Section 2.3.3).

Out of such a study, the degree to which each of these factors is common or mutually exclusive with S becomes measurable. In other words, the SSS could help settle the question as to the precise overlap between user satisfaction and the overall D & M models of system success. It is entirely possible, for instance, that a large enough sample of users will mention in their complaining, factors indicative of *all* the constructs listed above. That would suggest that in fact, user satisfaction is either synonymous with system success or is the most significant contributor to it. Of course, other results are possible and a range of similar studies could add a great deal of insight to both D & M models.

6.6 Summary of Chapter 6

6.6.1 Conclusions drawn directly from the results

This chapter set out first to identify the present study's contribution to knowledge. Significant amongst these was new rules for system development (see Sections 6.2, 6.2.4 and 6.3.3.3). Other immediate conclusions were as follows:

- User satisfaction tends to rise linearly over the period of system usage;
- Matching users with analysts of similar cognitive styles will probably reduce overall user dissatisfaction, but the result could be weaker than expected;
- the cognitive gap had a particularly strong negative impact in the neighbourhoods of 85 and 652 days when users have just begun using systems or when they are about to stop using them;
- Innovative analysts are more associated with user dissatisfaction than the reverse; and
- User perceptions of the severities of individual problems with time, decrease with time, approximately according to the reciprocal and exponential decay models.

6.6.2 Secondary conclusions and consequent suggestions

In section 6.3, this study suggests a new model for system usage and development, which adapts Herzberg's two-factor theory of motivation to a model based on a simple mechanical machine (see Section 6.3.1). In essence, this proposed mechanical model identifies motivational drive, estimable resistance and inestimable resistance as parallels to the physical concepts of motivational force, inertia and friction (see Section 6.3.1 and Figures 21 and 22). Both estimable and inestimable resistance are measurable by way of dissatisfiers in the form of weighted user complaints. This study found empirical evidence for the proposed model as applied to system usage (see Section 6.3.2), but concedes that further research is required to substantiate it for system development (see Section 6.5.6). In Section 6.3.3, recommendations, based on the previous two sections, are made for the benefit of IS practitioners.

In Section 6.4, this chapter gives two other achievements of the present study: the development and validation of the SSS instrument and S-statistic (see Section 6.4.1), and the successful application of Kirton' A-I cognitive theory in the field of information systems (see Section 6.4.2).

In Section 6.5, this chapter discusses potential areas for further research. In brief, these are:

- Replication of the present study as it stands (see Section 6.5.1);
- Further investigation of the rectilinear time-series model for overall user satisfaction (see Section 6.5.2);
- Validation of the impacts of the analyst/user cognitive gap generally over system usage life, and specifically in the two critical regions in the neighbourhoods of days 85 and 652 (see Section 6.5.3);
- Further validation of the system satisfaction schedule (SSS), either to help it become more widely recognised as a standard research tool or to find reasons to modify it (see Section 6.5.4);
- Confirmation or modification of conjectures made in this study for system development teams larger than the one user and one analyst cases investigated in this study (see Section 6.5.5);
- Validation, modification and/or extension of the use of the proposed machine model (see Section 6.5.6);
- Further investigation into the trends of perceived problem severities (see Section 6.5.7); and
- The contribution of user satisfaction to system success (see Section 6.5.8).

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Appendix 1.1

Format of the Kirton Adaption-innovation Inventory (KAI)*

Respondent Details
Date
Name
Age Sex
Occupation/Title
Department
Educational Status
Other

KAI RESPONSE SHEET

IMPORTANT
- Complete 'Respondent Details'
- Answer all questions
- Use ball point pen and press hard

Guidance Notes
We all find it necessary to present a particular image of ourselves consistently over a long period. In some cases this proves easy as we are like this; sometimes it is very difficult as we are not like this at all.

For instance, some of us are early risers. It is easy for such people to present the image of good timekeepers at work. So if you are an early riser and were asked how easy or hard it is for you to present an image at work of a good timekeeper you would put a clear cross on the scale below on or near 'Very Easy'.

Very Hard · Hard · Easy · Very Easy

. . . . X . .

If you are the extreme other sort, you would find being on time every morning for a long period difficult, and you may well put a cross on the scale at the 'Very Hard' end.

Please indicate the degree of difficulty (or ease) that would be required for you to maintain the image, consistently for a long time, that is asked of you by each item below.

How easy or difficult do you find it to present yourself, consistently, over a long period as:

	Very Hard	Hard	Easy	Very Easy
1) A PERSON WHO IS PATIENT.				
2) A PERSON WHO [illegible]				
3) A PERSON WHO [illegible]				
4) A PERSON WHO [illegible]				
5) A PERSON WHO [illegible]				
6) A PERSON WHO [illegible]				
7) A PERSON WHO [illegible]				
8) A PERSON WHO [illegible]				
9) A PERSON WHO [illegible]				
10) A PERSON WHO [illegible]				
11) A PERSON WHO [illegible]				
12) A PERSON WHO [illegible]				
13) A PERSON WHO [illegible]				
14) A PERSON WHO [illegible]				
15) A PERSON WHO [illegible]				
16) A PERSON WHO [illegible]				
17) A PERSON WHO [illegible]				
18) A PERSON WHO [illegible]				
19) A PERSON WHO [illegible]				
20) A PERSON WHO [illegible]				
21) A PERSON WHO [illegible]				
22) A PERSON WHO [illegible]				
23) A PERSON WHO [illegible]				
24) A PERSON WHO [illegible]				
25) A PERSON WHO [illegible]				
26) A PERSON WHO [illegible]				
27) A PERSON WHO [illegible]				
28) A PERSON WHO [illegible]				
29) A PERSON WHO [illegible]				
30) A PERSON WHO [illegible]				
31) A PERSON WHO [illegible]				
32) A PERSON WHO [illegible]				
33) A PERSON WHO [illegible]				

PLEASE CHECK THAT YOU HAVE ANSWERED ALL 33 QUESTIONS

014656

Copied from the KAI response sheet by permission of the author, Dr Micahel J. Kirton (see acknowledgements).

* Since the KAI is not in the public domain, all but the contents of the first item have been masked. To obtain full copies of the KAI and related material, kindly approach:
Dr Michael Kirton, The Occupational Research Centre, "Cornerways", Cardigan Street, Newmarket, Suffolk CB8 8HZ, UK. E-mail: m.j.kirton@kaicentre.com .

Appendix 1.2

System Satisfaction Schedule

System Name:…..

Organization: ....

System Type/Description: ....

....……...

Installation ("going live") Date: ....

User: (name not obligatory): ....

Physical Address/Office: .... Phone: ....

Other Contact Details: E-Mail: .... Fax: ....

User Details:

1) Date of Birth: ....

2) Gender: ....(M/F)

3) Rank/Post Description: ....

4) Employed by your organization since (Date): ....

5) How much time have you spent on using and/or on planning the system? ....

Analyst/Developer: (name not obligatory): ....

Physical Address/Office: .... Phone: ....

Other Contact Details: E-Mail: .... Fax: ....

Analyst/Developer Details:

1) Date of Birth: ....

2) Gender: ....(M/F)

3) Employed by your organization since (Date): ....

4) Worked as an Analyst/Developer and/or Programmer since (Date): ....

5) About how much time have you put into the above system? .... hours / days / week / months

(circle most appropriate time unit)

Page 2

Please rate your satisfaction with the system on the following scale:

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Extremely	*Quite Dissatisfied*	*Slightly*		*Slightly*	*Quite Satisfied*	*Extremely*

Please enumerate all the problems which you or others find with the system.*

** To be asked at initial interview only.*

Problem Severity Scale

(7)	(6)	(5)	(4)	(3)	(2)	(1)
an extremely serious/totally insoluble problem	*a very serious problem*	*a serious problem*	*a rather serious problem*	*a significant problem*	*a slight problem*	*no real problem*

	1	2	3	4	5	6	7	8	9	10	11	12
Date												
Satisfaction rating												
*System still in use (y/n)	*N/A*											
-with same user (y/n)	*N/A*											
**-with same developer (y/n)	*N/A*											

Now please rate each of these problem-areas on the Problem Severity Scale *(see bottom of Page 2)*

Total:												

If the system has been discontinued or is no longer in use by the original user, ascertain:

1) reasons why: ....; and

2) the date on which usage stopped: ....

****If the Analyst/Developer has changed or has ceased to be involved, please record relevant details below:***

Name of last Developer	Involved until (Date)	Name of new Developer	Involved from (Date)	New Developer's phone

Page 4

Instructions For Interviewers

The **System Satisfaction Schedule** (SSS) instrument is a means whereby user opinion of system success can be measured on an on-going basis.

First contact is made with the user through a face-to-face interview. Demographic information is recorded on Page 1 for both the user and key Analyst/Developer. The user's opinions of the system in question are then recorded on Page 2 and in Column 1 of Page 3.

Follow-up interviews are made telephonically at approximately three-month intervals. At each of these, the user reviews, expands and/or modifies his/her responses of the previous interview. The modified responses are recorded in Columns 2-12 of Page 3. New comments may be made and rated at the follow-up interviews.

Initial Face-To-Face Interview

1. Stress to the user that all his/her responses will be kept completely confidential.
2. Explain in simple terms the outline of the research to the user. Answer questions and address concerns expressed.
   Explain to the user that he/she will be involved in short follow-up phone calls at approximately three-month intervals.
3. Show this form to the user. Take the approach that you and the user are to complete the SSS together.
4. Obtain as much of the information required on Page 1 as possible from the user, including details of the person who in the user's view, is the Analyst/Developer or key Analyst/Developer. Mention that although the Analyst/Developer will be interviewed, none of the contents of this form will be made available to him/her.
5. Open the SSS form to Pages 2 and 3, and enter the **Date** in the first white cell of Column 1 on Page 3.
6. Ask the user for an overall rating of the system as follows:
   In general, are you satisfied or dissatisfied with the system?
   If the user specifies that he is generally **satisfied**, ask him to refine his choice thus:
   Would you say that you are ***slightly, quite*** *or* ***extremely*** *satisfied with the system?*
   Record the corresponding rating (5, 6 or 7) in the second (grey) cell of Column 1 on Page 3.
   Proceed similarly to record a rating of 3, 2 or 1 respectively if the user clains to be generally **dissatisfied** with the system.
   If the user declines to specify general satisfaction/dissatisfaction, obtain a rating of 5, 3or 4 respectively by asking:
   Would you say that you are ***slightly satisfied*** with the system, ***slightly dissatisfied*** with it, or ***definitely neutral***?
7. Ask the user to list problems with the system as follows:
   Please enumerate all the problems which you or others find with the system.
   I am going to record these briefly, so I may need to ask you to pause from time to time.
   Try to record a summary of each problem in two lines (one grey, one white).
   If there is not enough space on one form, continue on another.
   Do not suggest complaints to the user, even if he/she so requests.
   If, in your opinion, the user repeats a problem during the interview, respond as follows:
   I seem to have misunderstood, because I cannot tell the difference between that problem and a previous one you mentioned, which I have down as...
   then read the previous problem back to the user. Allow the user to withdraw the complaint or explain why it is different from the previous one. If the user insists that there is a difference, record the 'repetition' as a separate complaint.
8. Once all the problems have been recorded, each needs to be verified and rated on the Problem Severity Scale. The ratings are then to be recorded in the corresponding cell of Column 1 on Page 3. Say to the user: *I shall now read my summaries of each problem back to you for checking. Once you are sure that I have recorded a problem correctly,I will ask you to rate its severity.*
   Read the first problem, and allow the user to verify your summary. Alter where necessary, then say:
   Would this problem best be described as ***a slight problem, a rather serious problem*** *or* ***a very serious problem****?*
   These correspond to severity ratings of 2, 4 and 6 respectively. Ask the user for a refined response out of his/her choice and one to either side of it on the Problem Severity Scale. For example, if the user selects (4) **a rather serious problem**, say: *Would it be best described as* ***a serious problem, a rather serious problem*** *or* ***a significant problem****?* Hence obtain a rating of 5, 4, or 3 and enter this in the **first corresponding cell** in Column 1.
9. When taking leave of the user: thank him/her for his/her assistance; remind him/her that telephonic interviews will follow, and leave copies of the two-response scales in his/her possession for use during these interviews.

NB: 1) SCAN ALL YOUR COMPLAINT SUMMARIES FOR LEGIBILITY! THESE HAVE TO BE READ BACK TO THE USERS LATER, POSSIBLY BY ANOTHER PERSON. THEY MUST THEREFORE BE CONCISE AND CLEAR.
2) MAKE NOTES IMMEDIATELY AFTER THE INTERVIEW OF ANY UNEXPECTED AND UNUSUAL CIRCUMSTANCES/OCCURENCES.

Telephonic Interviews

1. At the appropriate time (3 months since initial interview or last telephonic interview), phone the user (number should have been recorded on Page 1). Remind the user of the last interview and system under consideration. If the user cannot be interviewed at that moment, make an appointment for you to phone back.
2. Refer the user to his/her copy of the rating scales. If the user has lost these, offer either to dictate them over the phone, or to Fax them.
3. Fill in the **Date** at the top of the appropriate column on Page 3 (e.g. Column 2 for first telephonic interview).
4. Ask whether or not the system is still used by the user and complete the relevant header cells. If not, ascertain the reason or reasons in as much detail as possible, and the discontinuance date, then complete the items * at the bottom of Page 3. Ask whether or not the Analyst/Developer has changed or ceased to be involved and complete the relevant header cell. In either event, complete the relevant table cells ** at the bottom of Page 3.
5. Read each problem back to the user which was current at the previous interview. Specify the last rating, and ask the user to re-rate it on the Problem Severity Scale. Use
   the two-tiered approach described in 8 above. Enter the result in the appropriate cell of the appropriate column on Page 3.
6. If the previous rating was (1) (*no real problem*), ask: *Is this problem worth further consideration or not?*
   If the user specifies **not**, rate the problem as zero and do not raise it at subsequent interviews.
7. After all ratings have been revised, ask: *Are there any other problems which have become apparent since the last interview?*
   If so, record the problem below the others on Page 2, and obtain a rating as described in 8 above.
8. Thank the user, and remind him/her that he/she will be contacted in about three months time.

NB: 1) SCAN ALL NEW COMPLAINT SUMMARIES FOR LEGIBILITY!
2)MAKE NOTES IMMEDIATELY AFTER THE INTERVIEW OF ANY UNEXPECTED AND UNUSUAL CIRCUMSTANCES/OCCURENCES.

Appendix 2.1

Behaviour descriptions of adaptors and innovators

Adaptor	Innovator
Characterized by precision, reliability, efficiency, methodicalness, prudence, discipline and conformity.	Seen as undisciplined, thinking tangentially, approaching tasks from unsuspected angles.
Concerned with resolving problems rather than finding them.	Could be said to discover problems and discover avenues of solution.
Seeks solutions to problems in tried and understood ways.	Queries problems' concomitant assumptions; manipulates problems.
Reduces problems by improvement and greater efficiency, with maximum of continuity and stability.	Is a catalyst to settled groups, irreverent of their consensual views; seen as abrasive, creating dissonance.
Seen as sound, conforming, safe, dependable.	Seen as unsound, impractical; often shocks his opposite.
Liable to make goals of means.	In pursuit of goals, treats accepted means with little regard.
Seems impervious to boredom, seems able to maintain high accuracy in long spells of detailed work.	Capable of detailed routine (system maintenance) work for only short bursts. Quick to delegate routine tasks.
Is an authority within given structures.	Tends to take control in unstructured situations.
Challenges rules rarely, cautiously, when assured of strong support.	Often challenges rules; has little respect for past custom.
Tends to high self-doubt. Reacts to criticism by closer outward conformity. Vulnerable to social pressures and authority; compliant.	Appears to have low self-doubt when generating ideas, not needing consensus to maintain certitude in the face of opposition.
Is essential to the functioning of the institution all the time, but occasionally needs to be 'dug out' of his systems.	In the institution is ideal in unscheduled crises, or better still to help avoid them, if he can be controlled.
When collaborating with Innovators:	**When collaborating with Adaptors:**
Supplies stability, order and continuity to the partnership.	Supplies the task orientations, the break with the past and accepted theory.
Sensitive to people, maintains group cohesion and cooperation.	Appears insensitive to people, often threatens group cohesion and cooperation.
Provides a safe base for the Innovator's riskier operations.	Provides the dynamics to bring about periodic radical change, without which institutions tend to ossify.

Appendix 2.2

User Information Satisfaction Short Form (UIS)

(Baroudi, Olson & Ives; in Baroudi & Orlikowski, 1988)

INSTRUCTIONS

1. **Check each scale in the position that describes your evaluation of the factor being judged.**
2. **Check every scale; do not omit any.**
3. **Check only one position for each scale.**
4. **Check in the space, not between spaces.**
   THIS, :_X_: NOT THIS :___X___:
5. **Work rapidly. Rely on your first impressions.**

Thank you very much for your cooperation.

1 Relationship with the EDP* staff

dissonant :___:___:___:___:___:___:___: harmoniuos

bad :___:___:___:___:___:___:___: good

2 Processing of requests for changes to existing systems

fast :___:___:___:___:___:___:___: slow

untimely :___:___:___:___:___:___:___: timely

3 Degree of EDP training provided to users

complete :___:___:___:___:___:___:___: incomplete

low :___:___:___:___:___:___:___: high

4 Users' understanding of systems

insufficient :___:___:___:___:___:___:___: sufficient

complete :___:___:___:___:___:___:___: incomplete

5 Users' feelings of participation

positive :___:___:___:___:___:___:___: negative

insufficient :___:___:___:___:___:___:___: sufficient

*EDP = Electronic Data Processing

6 Attitude of the EDP staff

cooperative	:___:___:___:___:___:___:___:	belligerent
negative	:___:___:___:___:___:___:___:	positive

7 Reliability of output information

high	:___:___:___:___:___:___:___:	low
superior	:___:___:___:___:___:___:___:	inferior

8 Relevancy of output information (to intended function)

useful	:___:___:___:___:___:___:___:	useless
relevant	:___:___:___:___:___:___:___:	irrelevant

9 Accuracy of output information

inaccurate	:___:___:___:___:___:___:___:	accurate
low	:___:___:___:___:___:___:___:	high

10 Precision of output information

low	:___:___:___:___:___:___:___:	high
definite	:___:___:___:___:___:___:___:	uncertain

11 Communication with EDP staff

dissonant	:___:___:___:___:___:___:___:	harmonious
destructive	:___:___:___:___:___:___:___:	productive

12 Time required for new systems development

unreasonable	:___:___:___:___:___:___:___:	reasonable
acceptable	:___:___:___:___:___:___:___:	unacceptable

13 Completeness of the output information

sufficient	:___:___:___:___:___:___:___:	insufficient
adequate	:___:___:___:___:___:___:___:	inadequate

Appendix 2.3

Two-factor test for end-users' IT acceptance: Perceived usefulness/Ease of use

(Davis, 1989. See Also, Chapter 2, Table 12)

PERCEIVED USEFULNESS

1. Using the system in my job has allowed me to accomplish tasks more quickly.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

2. Using the system is improving my job performance.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

3. Using the system in my job is increasing my productivity.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

4. Using the system is enhancing my effectiveness on the job.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

5. Using the system is making it easier to do my job.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

6. I am finding the system useful in my job.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

PERCEIVED EASE OF USE

1. Learning to use the system was easy for me.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

2. I find it easy to get the system to do what I want it to do.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

3. My interaction with the system is clear and understandable.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

4. I am finding the system flexible to interact with.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

5. I am finding it easy to become skilful at using the system.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

6. I am finding the system easy to use.

likely								**unlikely**
	extremely	**quite**	**slightly**	**neither**	**slightly**	**quite**	**extremely**	

Appendix 2.4

Resistance-Score (R-Score) Instrument

(entitled, "System Satisfaction Schedule", (Mullany, 1989))

System Name: ....

Organization: ....

1) Age: ....

2) Gender: ....(M/F)

3) User KAI: ....

4) For how long have you been employed by your organisation? ....

5) For how long have you worked with computers? ....

6) For how much time have you been involved with ……………………………. (analyst's name) regarding the abovementioned system?

   ……………………………………………..

7) How much time have you spent interacting with the abovementioned system?

   ………………………………………………

User Problem Schedule

Please enumerate all the Problems which you consider or heard had occurred during the implementation and/or early life of the system.

____

____

____

____

____

____

____

____

Now please rate each of these problem-areas as follows:

(7)	(6)	(5)	(4)	(3)	(2)	(1)
an extremely serious/totally insoluble problem	*a very serious problem*	*a serious problem*	*a rather serious problem*	*a significant problem*	*a slight problem*	*no real problem*

Appendix 2.5

End-User Computing Satisfaction Instrument

(Doll and Torkzadeh,1988)

	(5)	(4)	(3)	(2)	(1)
	Almost always	**Most of the time**	**About half of the time**	**Some of the time**	**Almost never**
Does the system provide the precise information you need?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Does the information content meet your needs?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Does the system provide reports that seem to be just about exactly what you need?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Does the system provide sufficient information?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Is the system accurate?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Are you satisfied with the accuracy of the system?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Do you think that the output is presented in a useful format?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Is the information clear?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Is the system user-friendly?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Is the system easy to use?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Do you get the information you need in time?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Does the system provide up-to-date information?	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**

Appendix 2.6

INSTRUMENT: Performance in Information Quality of E-Portals

(Cheung and Lee, 2005)

The measures of this research were borrowed from McKinney et al.'s study with modifications to fit the specific context of e-portal. Measures of Understandability (UN), Reliability (RE), Usefulness (USE), Access (ACC), Usability (USA), and Navigation (NAV) were phrased as questions on a seven-point Likert scale, from 1=strongly disagree to 7 = strongly agree.

Understandability (Strongly Agree to Strongly Disagree)
UN1 The information on e-portal is *clear in meaning*
UN2 The information on e-portal is *easy to comprehend*
UN3 The information on e-portal is *easy to read*
UN4 In general, information on e-portal is *understandable for you to use*

Reliability (Strongly Agree to Strongly Disagree)
RE1 The information on e-portal is *trustworthy*
RE 2 The information on e-portal is *accurate*
RE 3 The information on e-portal is *credible*
RE 4 In general, information on e-portal is *reliable for you to use*

Usefulness (Strongly Agree to Strongly Disagree)
USE1 The information on e-portal is *informative to your usage*
USE2 The information on e-portal is *valuable to your usage*
USE3 In general, information on e-portal *is useful for you to use*

Performance in System Quality of e-portal

Access (Strongly Agree to Strongly Disagree)
ACC1 e-portal is *responsive to your request*
ACC2 e-portal is *quickly loading all the text and graphic*
ACC3 In general, e-portal is *providing good access for you to use*

Usability (Strongly Agree to Strongly Disagree)
USA1 e-portal is *having a simple layout for its content*s
USA2 e-portal is *easy to use*
USA3 e-portal is *well organized*
USA4 In general, e-portal is *user-friendly.*

Navigation (Strongly Agree to Strongly Disagree)
NAV1 e-portal is *being easy to go back and forth between pages*
NAV2 e-portal is *providing a few clicks to locate information*
NAV3 In general, e-portal is *easy to navigate*

Satisfaction
SAT1 a. [Semantic differential scale from 1 = very dissatisfied to 7 = Very satisfied]
SAT2 b. [Semantic differential scale from 1 = very displeased to 7 = Very pleased]
SAT3 c. [Semantic differential scale from 1 = frustrated to 7 = Contented]
SAT4 d. [Semantic differential scale from 1 = disappointed to 7 = Delighted]

Appendix 2.7

Herzberg's Two Factor Theory of Human Motivation

Herzberg's theory was an extension of Maslow's *Hierarchy of needs theory*. As the reader may be aware, Maslow proposed that motivation is brought about by an individual's desire to satiate *needs* (Maslow, A. H., 1943, Maslow, A. H., 1964). According to Maslow, there are five classes of needs, occurring in an hierarchy and represented as a pyramid (see Figure 23 below). In principle, a need does not become *salient* to the individual until all the needs below it are met (Maslow, 1943, 1964).

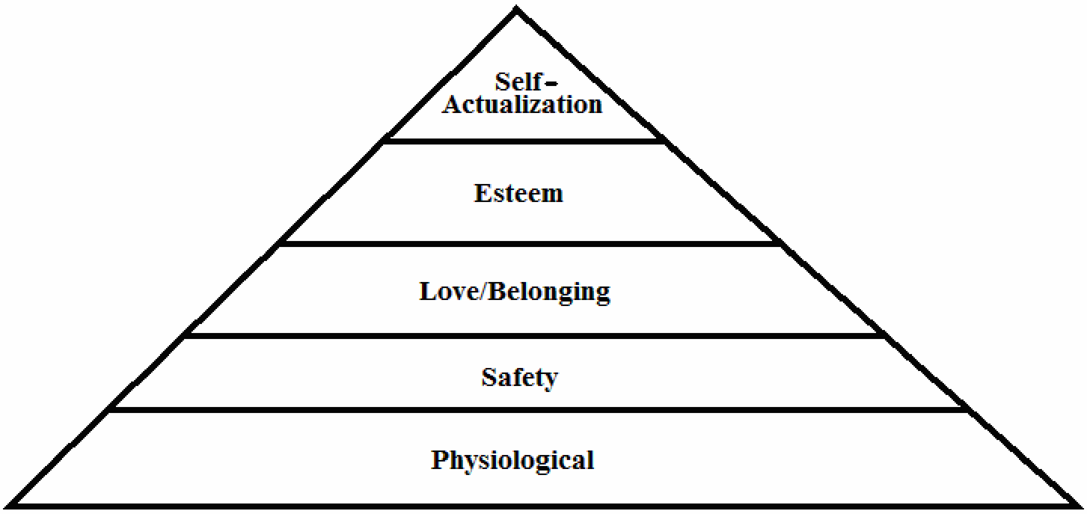


Figure 23: Maslow's Hierachy Of Needs

Herzberg's *Two Factor Theory of Human Motivation* (Herzberg, Mausner and Snyderman,1959) is built on the prior theory of Maslow (1948, 1964). Herzberg claims that the motivation of people in the workplace is affected by *two* broad classes of factors, *motivators* and *hygiene factors* (Herzberg, et al,1959). Motivators are positive reinforcements, such as rewards, pertaining to *job content*. Dissatisfaction, he claims, is caused by the absence of hygiene factors, which pertain to the quality of the work environment and which therefore relate to *job context*. Employee motivation requires both the presence of motivators and hygiene factors, the latter to avoid demotivation. Basic to this theory is the notion that only motivators can motivate. The presence of a hygiene factor does not motivate, but its absence will demotivate (Herzberg et al., 1959).

Examples of hygiene factors are, satisfactory working conditions, adequate salary, a degree of status, job security and congenial human relations. Motivators, on the other hand, are such things as, achievement, recognition, responsibility, promotion and opportunities for personal growth (Herzberg et al., 1959).

Combinations of hygiene factors and motivators suggest four work scenarios, which may be represented in a 2x2 matrix, thus:

	High Motivation	**Low Motivation**
High Hygiene	**Best-case Scenario** Employees are highly motivated and have few complaints	Employees are not highly motivated, but have few complaints
Low Hygiene	Employees are motivated but do a lot of complaining.	**Worst-case Scenario** Employees are unmotivated and do a lot of complaining.

(Herzberg et al., 1959)

A significant outcome from this theory for the current study is that *employee complaints* are seen as *symptoms* of missing hygiene factors; a relevant claim when investigating instruments based on employees' opinions and complaints.

Table 36 gives lists of typical motivators and hygiene factors as outlined by Hertzberg, et al. (1959), and some contemporary authors (Downey (2005), Rynes, Gerhart and Parks (2005), and White and Olson (2004)).

Table 36: Motivators And Hygiene Factors, According To Herzberg's Two-factor Theory of Motivation

MOTIVATORS	HYGIENE FACTORS
Achievement in the job Recognition of good work Challenging work	No company bureaucracy No stringent supervision Adequate salary
Responsibility for one's own job Advancement opportunities Growth skills	Good relations with co-workers Good working conditions Adequate job security

Criticism of Herzberg's Two Factor Theory followed. Caston and Braito (1985), for example, claim that Herzberg's theory tries to explain job satisfaction, rather than work motivation, but does not successfully measure job satisfaction. (Caston and Braito, 1985). However, Knoop (1994), in an empirical study involving a sample of 386 personnel drawn from high schools, showed that

> "the variables Herzberg termed satisfiers, (achievement, recognition, the work itself, and responsibility) loaded clearly on the "intrinsic dimension" of "job satisfaction".

The results also suggested other factors that may contribute to satisfaction, such as, doing meaningful work, having influence over work, being able to use one's abilities and knowledge, having independence in doing one's work, contributing to society, receiving esteem from others, gaining job status, and having influence and pride in the organization. In short Knoop's (1994) results support and extended Herzberg's theory. Knoop (1994) in a separate study involving 607 elementary school teachers provided further verification of Herzberg's theory.

Locke (1983) rejected the idea that there can be two mutually exclusive sets of factors which satisfy or dissatisfy. In other words, some of Herzberg's hygiene factors can motivate while some motivators, if missing, can demotivate. It will be noted that this author identifies satisfaction with motivation and dissatisfaction with de-motivation; an entirely reasonable position. He also confirms that "Herzberg's theory. . does provide a useful distinction between physical and psychological needs and identifies cognitive growth as a major psychological need that can be fulfilled through work" (Locke, 1983). However, the link between employee satisfaction and motivators, or between employee dissatisfaction and missing hygiene factors, is called into question.

2.7.1 Currency and plausibility of Herzberg

In general, Herzberg's theory remains credible and can be found in recent research literature across several disciplines. Downey (2005), for instance, refers to his work in a conference paper entitled, "A framework to elicit the skills needed for software development". Rynes, Gerhart and Parks (2005) refer to his theory in their literature survey and discussion of performance evaluation and pay for performance. White and Olson (2004) based the literature review for their empirical study entitled, "Factors Affecting Membership in Specialty Nursing Organizations" on Herzberg's theory.

Herzberg's theory is also taught as integral parts of psychological, educational and management studies at credible universities. For example, see Harris's (2005) course material on organisational theory, University of Victoria, Canada. Cheung & Lee (2005) in their paper entitled, "The Asymmetric Effect of Website Attribute Performance on Satisfaction: An Empirical Study", emphasise the parallels between Herzberg's factor classifications and some types of factors in market research. They state,

> "we can also classify our web attributes into utility-preserving (hygiene) factors or utility-enhancing (motivation) factors",

after Herzberg. However, with the exception of this article and one other discussed below, Herzberg's theory in information systems research in recent times has received negligible attention. In justification, several scholarly sources were scanned for any significant references to Herzberg's theory. Only three instances, as listed in Table 37, were found.

Table 37: Articles found to contain significant references to Herzberg's Theory in recent IS literature

Date	Authors	Publication
2005	Cheung & Lee	*Proceedings of the 38th Hawaii International Conference on System Sciences*
2000	Zhang & Von Dran	*Journal of the American Society for Information Science*
1996	McLean, Smits & Tanner	*Information & Management*

Appendix 3.1

Descriptive statistics used in this study

(The material in this appendix has been summarised from Campbell, R. B. (2005) of the University of South Australia.)

3.1.1 Descriptive statistics

The objective of a descriptive statistic is to provide a value which gives an overall description of a set of data. Measures of location, which provide some overall idea of the magnitude of the data, are generally used. The most common of these are the Minimum, Maximum, Median and Mean. One other measure, the mode, was not employed in the present study as there were only 3 to 7 observations made for each of the system samples. In such small samples, there frequently is no mode, ruling out overall sample comparisons.

3.1.2 Minimum and Maximum

The minimum and maximum are, respectively, the smallest and largest values in a data set.

3.1.3 Median

The median is the middle value if there is an odd number of data points. If there is an even number of data, the median is half way between the two middle values. To determine this statistic, data need to be ranked in order.

3.1.4 Mean

The mean is the sum of all the data values divided by the number of data. The mean tends to be affected more by extreme data values than the median. However, when extreme values are important, the mean may be the better descriptive statistic.

Appendix 3.2

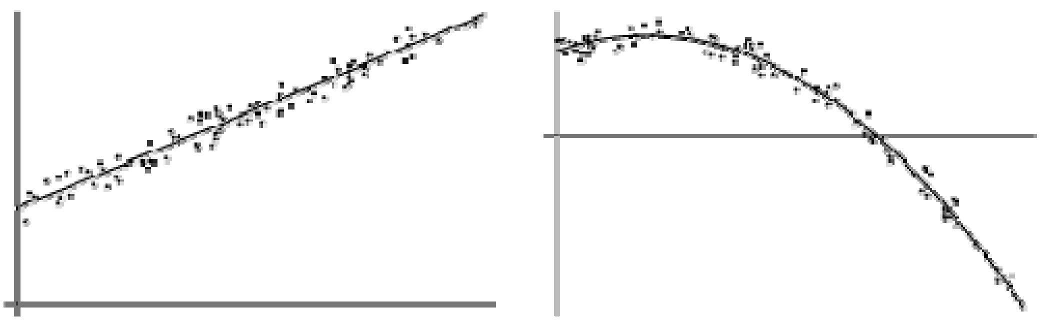
Mathematical functions used as time-series candidates in this study

(Readers who have completed a first-year university mathematics course may be au fait with the content of this appendix.)

3.2.1 Simple analytic functions

It is evident from Research Question 3 and 4 (see Chapter 2, Sections 2.4.3 and 2.4.4) that this study needed to use statistical tools based on trends in data measured over time; that is, *trend analysis* (see StatSoft Inc., 2004). There are a number of simple mathematical functions used extensively for exploring trends in data, by way of best fitted curves (Thomas, Finney, Weir & Giordano, 2001). The advantage of fitting these functions is that their behaviour is well-known and thus they can describe the trends, or partial trends, in time-series data. Weisstein (2000) notes that the *least squares* method is appropriate for the determination of the best fitting curve of most simple analytic function types. He supplies the following diagrams for clarity:

Figure 24: Best-fitting curves for two sets of time-series data



Hopkins (2000), in a discussion of advanced statistical techniques identifies polynomial expressions as providing adequate models for many types of trend over time. These are defined as functions of the form:

$$y = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 \ldots$$

where a_0, a_1, a_2, a_3, $a_4 \ldots$ are constants and t is time.

He notes two special cases of this:

the linear function: $y = a_0 + a_1 t$ and

the quadratic function: $y = a_0 + a_1 t + a_2 t^2$.

He suggests that with normal curve-fitting one rarely needs to go to a higher degree of polynomial than the second; that is, than a quadratic function (Hopkins, 2000). In other words, two obvious models to investigate in any trend analysis will be the linear and the quadratic models. However, Hopkins (2000) also notes the importance of observing whether or not a given type of curve is a *reasonable candidate* for a best-fitting curve, based on visual observation of the plotted data.

In the case of this study, Research Question 4 suggests problem severity *decreasing* with time, hence linear functions selected should have *negative* slopes, while quadratic function candidates should have *positive* quadratic terms (of the form at^2) and *minimum* values (Thomas, Finney, Weir and Giordano, 2001).

Of course, one should not consider a model unless there is some rationale for its plausibility. Analytic functions rejected *a priori* on this basis were the trigonometric functions, since these suggest seasonal or cyclical trends (Thomas, Finney, Weir and Giordano, 2001) and no reason to expect such trends in the data could be justified.

Another curve which they mention as a potential candidate is the exponential decay model:

$y = a e^{-kt}$, where a and k are constants and e is Euler's number; 2.7182818 . . .

Yet another analytic function yielding a decreasing curve over time is the inverse proportion model (derived from Thomas, Finney, Weir and Giordano, 2001):

$y = k / t$, where k is a constant.

With this in mind, four simple mathematical models, which possibly reflect the way perceived problem severity may decline with time, were identified.
These were:

- Rectilinear (straight-line) with a negative slope;
- Quadratic;
- Reciprocal; and
- Exponential decay.

Each is dealt with in turn.

3.2.2 The rectilinear model

According to this model, a value associated with some given phenomenon changes at a constant rate with time (Thomas, Finney, Weir and Giordano, 2001). The level of sand in the upper chamber of an hour glass is an example of this. If the perceived severity of a system problem obeys this law, the perceived severity would fall by a constant amount per unit of time. With little else to go on, a rectilinear drop in perceived problem severity did not seem particularly unlikely, so this model was accepted as plausible. The general expression is:

$R = R_0 + m\,t$ (Thomas, et al. 2001 give an equivalent form)

where R is the measure of dissatisfaction, t is time, R_0 is the vertical (y) intercept and m the slope of the straight line.

3.2.3 The quadratic model

If the graph of perceived severity decline is not rectilinear, then it may either be curvilinear or random or some combination of the two. In the random case, by definition no pattern of behaviour is present. It has been shown (Finney, Weir and Giordano, 2001) that the quadratic function can approximate a large number of curves. This results from the fact that it can be expressed as a polynomial of the second degree, namely:

$a_0 + a_1 t + a_2 t^2$.

When expressed in this form, it may approximate the value of a power series of the type:

$$a_0 + a_1 t + a_2 t^2 + a_2 t^3 + a_2 t^4 + a_2 t^5 + a_2 t^6 \ldots.$$

if the series converges quickly after the third term to a negligible quantity (Thomas, Finney, Weir and Giordano, 2001). Power series of this kind are frequently simple analytical functions expressed as Taylor series. This train of thought suggested the quadratic model as a plausible option for application to perceived problem severity.

Quadratic functions tend to form symmetric curves about an *axis of symmetry* at which a *maximum* or *minimum* value is attained (Thomas, Finney, Weir and Giordano, 2001). For curve-fitting, and with the variables converted for measuring R on t, the following alternative form of the quadratic function is available. This is more tractable to handle than the previous form.

$$R = a\,(t - p)^2 + q$$

where a is the quadratic coefficient a_2, p is the axis of symmetry and q is the minimum value (after Thomas, Finney, Weir and Giordano, 2001). It is plausible enough that a quadratic function may pattern the behaviour of a declining perceived problem severity, at least down to its minimum.

3.2.4 The reciprocal model

This model proposes that the phenomenon under investigation has at its heart an *inverse proportion* (Finney, Weir and Giordano, 2001). In the case of perceived severity, this implies that the longer a user experiences a problem the less severe its perception will tend to become. This may be either because the user develops coping skills or because the problem is actively addressed and ameliorated. As it is plausible that a user will find a problem to reduce in proportion to the length of time he/she experiences it, this model was also selected for testing. In general a reciprocal function has two asymptotes; one vertical and one horizontal. With the unknowns transformed for the plotting of R on t, a general expression for this is:

$$R = \frac{k}{t + a} + \ell$$

where -a is the vertical asymptote, k is a scaling constant and ℓ is the horizontal asymptote.

3.2.5 The exponential decay model

In general, an exponential decay occurs when some quantity is reducing, and the instantaneous rate of decay is directly proportional to the quantity remaining (Giordano, et al., 2001). Radioactive decay obeys such a law. The more milligrams of non-decomposed matter there are, the more milligrams decay per unit of time. If perceived problem severity follows such a law, it means that the reduction in perceived severity a day (say) is proportional to the severity perceived. In other words, a problem which is perceived to be very severe will rapidly lose its perceived severity. A problem of minimal perceived severity, however, will only reduce slowly with time. Once again, this model is plausible, on the assumption that people tend to address severe problems quickly, while minimal problems may be tolerated for some time. This model makes use of the *exponential function* e^t, where e is the well-known mathematical constant 2.7182818. . . . Such functions usually have a horizontal asymptote, but no vertical one.

The general form is:

$$R = a\,e^{-kt} + \ell$$

where a is the initial value, k is the constant of proportionality and ℓ is the horizontal asymptote.

Appendix 4.1

Statistical tests used in this study

(Readers who have completed a first-year university statistics course may be au fait with most of the content of this appendix.)

4.1.1 Statistical formulae

Mathematicians and statisticians frequently use differing conventions in their expression of formulae. On occasion therefore, formulae and/or parts of formulae quoted in this thesis have been replaced by mathematical equivalents for the sake of overall consistency. Generally, population parameters have been expressed in Greek letters, while their sample statistic counterparts are given in their Latin equivalents. Of particular note, the symbols τ and ρ denote the association and correlation parameters in a bivariate *population*, while t and r represent the corresponding *sample* statistics.

4.1.2 Hypothesis-testing, levels of significance, powers of tests and estimates of parameter sizes

The statistical tests in this study are all significance level tests, based on the model:

H_0 (null hypothesis): Population Parameter, $\gamma = C$ (C a constant)

H_a (alternative hypothesis): $\gamma < C$ or $\gamma > C$ (one-tail test), or $\gamma \neq C$ (two-tail test)

(Kazmier, Staton & Fulks, 2003)

4.1.2.1 Significance levels

The *significance level* (α) is based on the *associated sample statistic*. α is the probability of rejecting the null hypothesis when the null hypothesis is, in fact, true. Consequently, the *lower* the value for α, the *greater* the probability that the alternative hypothesis is true, and the greater the significance of the test. In the literature, the upper limit $p = \alpha$, is set such that the significance associated with the statistic, p, is $\leq \alpha$ (Zar, 1999). Hence a result is significant at $\alpha = 0.05$ if $p \leq 0.05$. However, there are no purely statistical criteria for making a decision on an appropriate choice of α, and precedents have to be sought within the research discipline concerned, or within closely related disciplines. Consequently, the actual levels employed in this study were based on the opinions found in statistical, human science (including both psychological and sociological) and IS literature. These opinions are summarized in Table 38.

Table 38: Ratings of significance levels

Significance level	Statistic	Opinion(s) of significance	Type of scholarly literature source
p < 0.001	Kendall-t	**"very small" -Kendall (1970)**	Statistical
	Pearson r	**"significant" -Kirton (1999)**	Psychological
p < 0.010	Kendall-t	**"small" -Kendall (1970)**	Statistical
	Kendall-t	**"significant" - Zar (1999)**	Management
	Pearson r	**"significant" -Kirton (1999)**	Psychological
p < 0.050	Kendall-t	**"small" -Kendall (1970)**	Statistical
	Kendall-t	**"significant" -Zar (1999)**	Management
	Pearson r	**"significant. . caution. ." – Olson & Ives (1981)**	Information Systems
p > 0.100	Mean	**"not statistically significant" - Zar (1999)**	Information Systems

Based on the opinions of scholars as recorded in Table 38, the qualitative ratings listed in Table 39 were assumed for this study.

Table 39: Qualitative ratings assumed for significance levels

Significance level	Qualitative ratings		
p < 0.001	Highly significant;	Null hypothesis strongly rejected;	Alternative hypothesis strongly supported.
0.001 < p < 0.050	Significant;	Null hypothesis rejected;	Alternative hypothesis supported.
0.050 < p < 0.100	Not very significant;	No strong reason to reject null hypothesis;	Weak support for alternative hypothesis. Inconclusive result.
p > 0.100	Not significant;	No reason to reject null hypothesis;	No support for alternative hypothesis.

As far as the choice between one-tail and two-tail testing is concerned, two-tail tests seek an alternative hypothesis which proposes a *significant difference* (positive or negative) which challenges the null-hypothesis equality. If the alternative hypothesis proposes a one-directional inequality (greater than, or less than), then a one-tail test is used (Kazmier, Staton & Fulks, 2003). In general, one uses the one-tail option where the direction of a test is known or hypothesised. Where this is not known or cannot be hypothesised on reliable criteria, the two-tail test is appropriate (Zar, 1999).

4.1.2.2 Powers of tests

Baroudi and Olikowski (1989) call for the increased use of *powers of tests* in IS research, since without these, alternative hypotheses are too easily rejected, even though they may be true. Chin (1998), in an editorial on statistical power and related topics, suggests that only some 37% of published IS research includes estimates of statistical power.

The *power* of a significance level test is the probability of rejecting the null hypothesis when some other clear alternative is true (Zar, 1999). While the significance level, α, is the probability of *rejecting* the null hypothesis given that it is true, the probability β is assigned to the probability of *accepting* the null hypothesis when in fact, some other alternative is true (Zar, 1999). The *power* of the test is thus $1 - \beta$. Both β and $1 - \beta$ vary with the sample size, the particular alternative hypothesis chosen and the significance level, α. A low power biases a significance level test falsely in favour of the null hypothesis and can result in its acceptance when the alternative is true (Cohen, 1988). Acceptance of the null hypothesis under this condition is therefore called into question. Rejection, however, more strongly supports the alternative hypothesis, since the test rejects the null hypothesis *despite* its being biased in favour of the null hypothesis.

As an aid to the selection of the values for α and β, Cohen (1988) gives a formula for the *relative seriousness* (H) of the mistaken rejection of the null hypothesis to its mistaken acceptance, as:

$$H = \beta/\alpha$$

He gives the example of a test set at the 0.05 significance level with a power of 0.80. Then $\alpha = 0.05$ while $\beta = 1 - 0.80 = 0.20$. Hence $H = \beta/\alpha = 0.20/0.05 = 4$. In other words, mistaken rejection of the null hypothesis is considered *4 times more serious* in this research design than its mistaken acceptance. While Cohen offers this as an example, Baroudi and Olikowski (1989) note that the 0.05 significance level together with a power of 0.80 have become an ***accepted convention*** in the human sciences.

Basic to the process of power determination is the fixing of the *critical effect size*, as the minimum deviation from the null hypothesis which can be considered a viable alternative. This is determined by the researcher from prior knowledge and experience, and is a judgement call which, like the significance level itself, cannot be deduced solely on statistical grounds. Cohen (1988) and Kraemer and Thiemann (1987) provide tables and methods for calculating powers and related information for a variety of hypothesis tests at the 0.05 and 0.01 levels of significance. Where the present study has made use of powers of tests, the relevant methods and formulae have been given with the description of those tests below.

The success of a statistical test in terms of it's significance level and power is qualitatively summarised in Table 40.

Table 40: Significance and power: qualitative summary

	High Significance (small α)	**Low** Significance (large α)
Power **high** in relation to significance level	The result of the test is supported irrespective of whether acceptance or rejection of H_0 occurs.	If the test *accepts* H_0, test is not discredited. If the test *rejects* H_0, it is called into question.
Power **low** in relation to significance level	If the test *rejects* H_0, it is not discredited. If the test *accepts* H_0, it is called into question.	The result of the test is not supported.

From Table 40 it is evident that the determination of power is not always necessary. For instance, a low power alone does not discredit a significance level test which rejects the null hypothesis (Kraemer and Thiemann, 1987). Also, by reviewing the tables given for power in either Cohen (1988) or Kraemer and Thiemann (1987) it is clear that tests at significance levels of 0.05 or 0.10 which reject the null hypothesis usually do so at powers which are well under 95% or 99% respectively. In both cases, the seriousness of mistaken rejection of the null hypothesis to its mistaken acceptance, H, is ≥ 1, unless unrealistically high effect size indices are employed. In other words, it is usually not necessary to determine the powers of tests at the 0.05 or 0.10 significance levels if substantive rejection of the null hypothesis is all that the research design requires.

4.1.3 Normality of data samples

It is known that approximately normal distributions of data occur as a result of many kinds of experiments (Kazmier, Staton & Fulks, 2003). If a sample is approximately normally distributed, therefore, then the probability is that the measuring procedure is reliable. The converse, of course, is untrue. If a sample is not approximately normal, this does not discredit the measuring procedure, since the parent population itself could be far from normal for the measure concerned. Consequently, the presence of normally distributed data supports the measurement method as reliable. On the other hand, lack of normality yields no information regarding the reliability of the measuring technique. There is a further reason for seeking normal distributions when drawing inferences on population means. This is that the *central limit theorem* then applies for sample sizes ≥ 30 and that any associated statistics may then be regarded as *parametric*. The latter implies that the measure used exhibits a scientific notion of size, in the sense that height and weight do. A suspected lack of population normality may make the use of so-called non-parametric tests appropriate, where the *ranked order* of the data are used in place of the actual data themselves (Berenson & Levine, 1986).

Where required in this study the normality of univariate data samples were tested using a goodness-of-fit test of the Chi-square type. The reason for doing so was two-fold: to check the reliability of the measuring techniques used and to determine whether parametric or non-parametric tests were most appropriate in a variety of situations. The procedure tests normality of distribution as a *null hypothesis*. It gives rise to χ^2 values, which can be compared with critical values in tables (Zar, 1999). In accordance with Table 39, the levels of significance used to measure the extent of normality suggest that $p < 0.05$ implies a *significant departure* from normality. However, it requires determination of the power of the test to show where the test exhibits *no significant departure* (that is, approximately normal) (Cohen, 1988).

Berenson & Levine (1986) give the following procedure for the testing of the null hypothesis of population normality, given a random data sample drawn from that population. The mean and standard deviation of the population are estimated using the corresponding sample statistics. The appropriate normal curve is then drawn, and area cells are constructed as dictated by convenience (that is, theoretically quite arbitrarily). From standard normal distribution tables, the *expected* number of sample data fe_i in each cell can be determined. fo_i is used to denote the number of data *actually observed* in each cell. Hence for cell i, fe_i data are expected and fo_i data occur. Next, the χ^2 statistic is computed using the formula:

$$\chi^2 = \sum_{i=1}^{n} \frac{(fo_i - fe_i)^2}{fe_i}$$

where n is the number of cells.

In the case of this test, the null hypothesis is one of normality. Hence, if the χ^2 statistic is greater than a critical value tabulated for some predetermined level of significance, the data distribution is considered non-normal. Tables of critical values of the χ^2 distribution for various levels of significance and degrees of freedom are readily available (Berenson & Levine, 1986). There are, in the case of this test, *three degrees of freedom fewer* than the number of cells (Berenson & Levine, 1986).

Improvements in reliability can evidently be achieved in the above procedure by following certain recommendations made by Moore (1986). These recommendations (which were followed in this study) are as follows:

1. rather than making an arbitrary cell choice, cells should be chosen to be equiprobable; that is, there should be an equal probability of a random datum falling into any cell;
2. with equiprobable cells, there should be an average expected cell frequency of at least 1 when testing fit at the 0.05 level of significance, and at least 2 when testing at the 0.01 level of significance; and
3. there should be at least three cells. (Moore, 1986)

The levels of significance used to measure the extent of normality were based on Table 39, with $p < 0.05$ implying a significant departure from normality, and $p > 0.10$, with a power of 0.80, no significant departure (that is, approximately normal).

4.1.3.1 The need for power testing in χ^2 goodness-of-fit techniques

As discussed in Section 4.1.2.2 above, low powers of tests do not discredit significance level tests that reject the null hypothesis. However, in the present tests normality is inferred by *failure* to reject the null hypothesis. In other words, a low power would call into question a “successful” test of this type. Where used in the present study, therefore, these procedures were all subjected to power testing (see Section 4.1.2.2 for a discussion of power testing). A method for doing this is given by Cohen (1988). He provides tables of powers for tests at various levels of significance (α), numbers of cells (n), degrees of freedom ($\nu = n-3$), and effect size indices (w). The effect-size index (w) is determined from the population by the formula:

$$w = \sqrt{\sum_{i=1}^{n} \frac{(Po_i - Pe_i)^2}{Po_i}}$$

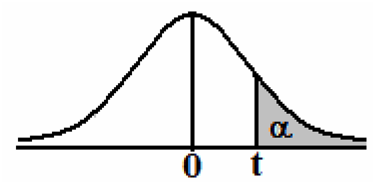
where n is the number of cells, Po_i are the observed proportions of the readings in each cell and Pe_i are the expected proportions (Cohen, 1988).

However, estimates of w can be made from prior results or post-hoc from values of w determined from the samples under investigation (Cohen, 1988).

As w is not a familiar index to researchers, Cohen suggests a convention based on three values of w: $w = 0.10$, $w = 0.30$ and $w = 0.50$, corresponding to the adjectives *small*, *medium* and *large* respectively (Cohen, 1988). He also intimates that the significance level for such tests should be set at a higher (less significant) position than 0.05, since the object of the test is to *look for* normality by demonstrating support for the null hypothesis. If the significance level is set at 0.10 to provide less bias in favour of the null hypothesis and then a power of 0.975 is selected, the probability of accepting the null hypothesis when false would be $1 - 0.975 = 0.025$. This would define a ratio of risk of false null rejection to false null acceptance as $0.025/0.10 = 0.25 = ¼$. In other words, this test would be four times more likely to reject the null hypothesis of normality when true than to accept the null hypothesis of normality when false. The 0.10 significance level test exhibiting 0.975 power is thus clearly biased in favour of the non-normality hypothesis. If the test cannot reject the null hypothesis under these conditions, then the hypothesis of normality is supported.

4.1.4 Student's t distributions

This family of symmetric distributions is widely used in inferential statistics where only samples smaller than 30 are available (Clark and Randall, 2004). Each t-distribution is identified by its *degrees of freedom* (ν), which is a positive integer in the range $\nu = 1$ to $\nu = \infty$ (Clark and Randall, 2004). The t-distribution for $\nu = \infty$ is identical to the standard normal (z) distribution. All the others have a mean of zero but a slightly larger standard deviation than 1: the smaller ν, the greater the standard deviation. In effect, t-distribution theory allows the sample standard deviation to be employed as an estimate of the population standard deviation, if the population can be assumed to be normal (Clark and Randall, 2004).



Tables of t-distributions are available which give *critical values* for t. A critical value of t traps a specific area α in the *upper tail* (Clark and Randall, 2004). The critical value of t (written $t_{\alpha, \nu.}$) has ν degrees of freedom, and bounds an upper tail area of α.

4.1.5 Confidence intervals for population means

A *confidence interval* lies between an upper and a lower *confidence limit*. These limits are equidistant from the sample statistic, each being a distance of one *confidence radius* away. Hence the formula:

Confidence limit = Sample Statistic ± Confidence Radius

When fixing the 1 - 2α confidence interval for the mean of a ***normal*** population, the Confidence Radius for small samples is given by:

$$\text{Confidence Radius} = t_{critical} \cdot \frac{s}{\sqrt{n}}$$

where n is the sample size (Clark and Randall, 2004) and $t_{critical}$ has n-1 degrees of freedom. In the case of S-Scores, the ***assumption of population normality*** was made after the S-Score tests for normality were successful (see Chapter 4, Section 4.4.1 and Table 20).

There is an equivalence between confidence interval determination and hypothesis-testing. Let a confidence interval for the population be determined at the 1 – 2α level, and pick any value μ_0 within this interval. Then the null hypothesis of $\mu = \mu_0$ cannot be rejected in favour of $\mu \neq \mu_0$ at $p = 2\alpha$. In other words, the determination of a 90% confidence interval for the population mean is equivalent to the testing of a two-tailed hypothesis on the population mean at p=0.10 for any hypothesised value within the confidence interval. As this study standardised hypothesis tests at p = 0.10, p = 0.05 and p = 0.01 (see Section 4.1.2 and Table 39 above), it also standardised confidence interval determination correspondingly at the 80%, 90% and 98% levels of confidence.

4.1.6 Testing hypotheses on the means of normal populations

Zar (1999) gives this procedure by way of the following model (see Section 4.1.2 for a general discussion of models).

For population mean μ from a normal population, the research model is:

H_0: $\mu = \mu_0$

H_a: $\mu > \mu_0$; $\mu < \mu_0$ (one-tail tests); or $\mu \neq \mu_0$ (two-tail test)

The test statistic is:

$$t = \frac{(\bar{x} - \mu_0)\sqrt{n}}{s}$$

where $\bar{x}$ is the sample mean, μ_0 some hypothesized population mean, s is the sample standard deviation and n is the sample size.

The number of degrees of freedom(ν) of t are given by:

$\nu = n - 1$, where n is the sample size.

To test the null hypothesis, the value of the test statistic t is compared against critical values in tables of the t-statistic (Zar, 1999). This procedure is valid even if the population is not normal, as a consequence of the *central limit theorem* (Zar, 1999). Hawkins and Weber (1980) suggest that the test is robust to a lack of sample normality if the sample size (n) equals or exceeds 30.

A further use that this test can be put to is to determine the efficacy of a treatment on people or things (Zar, 1999), for example, a slimming treatment. The weights of the participating subjects can be recorded before and after the treatment, and the *differences* analysed as a single sample (Zar, 1999). The two-sample means test given below in Section 4.1.11 is not suitable for this, since the parent populations are not independent.

4.1.7 The correlation co-efficient, r

The population Pearson product-moment correlation coefficient, or just the correlation coefficient, ρ, measures the strength of a rectilinear relationship in a population of bivariate data (Kazmier, Staton and Fulks, 2003). The parallel statistic for a sample, is denoted r. ρ and r lie between -1 and +1 inclusive. When they take the value 0, the data are *rectilinearly independent*, although they could have a strong *curvilinear* dependence.

The formula for calculating r for a given bivariate sample is given by Kazmier, Staton & Fulks, (2003) as:

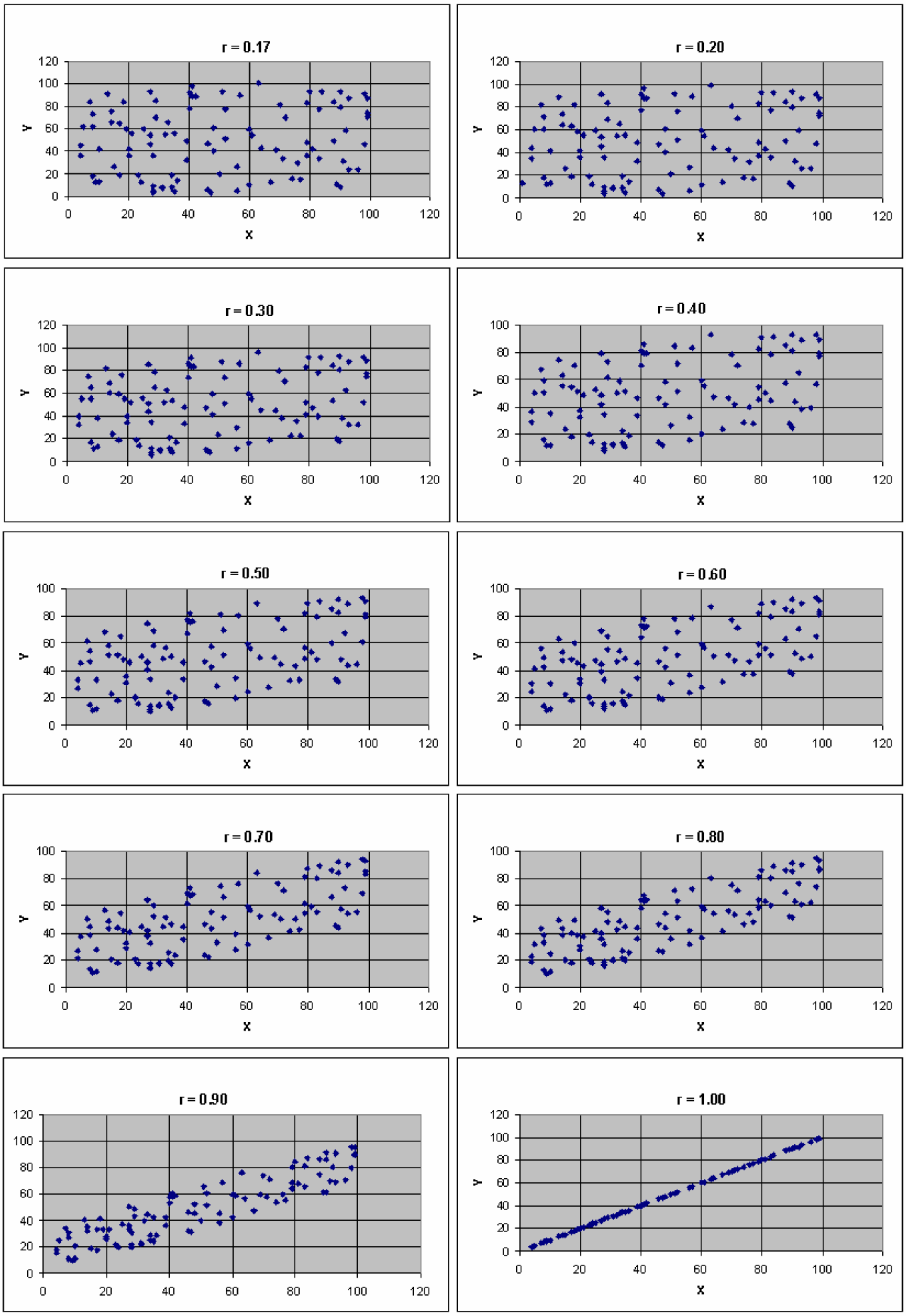
$$r = \frac{\sum(x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2}\sqrt{\sum(y_i - \bar{y})^2}}$$

Figure 25 (below) gives a visualisation of various values for the correlation co-efficient. As is evident from this, the linear relationship weakens quickly as r falls much below 0.8 and is barely discernable for sizes smaller than 0.3. The value of 0.8 has been corroborated as a functional minimum in some IS studies. Parkinson, Mullally and Redmond (2004), for example, in an attempt to measure the reliability of a two-scale cognitive style instrument, found Pearson product-moment correlations which were below what they called

> "the generally accepted value of r = 0.8"

(see Chapter 2, Section 2.2.2.1).

Figure 25: Visualisation of the correlation coefficient: sets of 100 bivariate data pairs with selected values for r



4.1.7.1 Formula for testing the significance of the correlation coefficient r

The significance of r is based on a model proposing a null hypothesis of independence in the population, thus:

H_0: $\rho = 0$

H_a: $\rho \neq 0$

The formula required to test the significance of r is given by Kazmier, Staton & Fulks (2003) as follows:

$$t_{n-2} = \frac{r}{\sqrt{(1 - r^2)/(n - 2)}} .$$

Where: n = sample size;

r = correlation coefficient as defined above; and

t_{n-2} is the Student's-t value with n-2 degrees of freedom.

As mentioned in Section 4.1.2, however, a highly significant result obtained from a large sample can be misleading. Suppose, for instance that a sample of 1,002 exhibits a correlation coefficient of 0.1. Then from the formula above,

$$t_{1000} = 0.1/\sqrt{(1 - 0.1^2)/1{,}000} = 3.5136$$

By comparing this with the appropriate value read from a table of Student's t, it will be seen that r is highly significant at p = 0.001 (for precedents, see Section 4.1.2 above. For a discussion of Student's t, see Section 4.1.4 above). However, the value of r = 0.1 is a weak result, being below 0.3 required for any linear relationship to be more than negligible (see Section 4.1.7 and Figure 25). In short, if the population correlation coefficient is accurately estimated as 0.1, it is of little consequence, no matter how "significant" the above test may suggest it to be.

4.1.7.2 Formulae for determining powers of significance level tests on r

Kraemer and Thiemann (1987) give formulae and tables for the power of significance level tests on r. These require what they term a *critical effect size index* (Δ). For determining the latter, they give the formula:

$$\Delta = (\rho - \rho_0)(1 - \rho\rho_0) .$$

If $\rho_0 = 0$, signifying independence, the formula reduces to:

$$\Delta = \rho .$$

If one takes an effect size of $\rho = 0.55$, which is the mean of the size-values of 0.3 and 0.8 discussed in the section 4.1.7, then $\Delta = 0.55$ for tests on the null hypothesis of independence. Δ and the desired power are then applied to Kraemer et al's (1987) 'Master Table'. This yields a parameter ν, which is related to sample size n (in this case) by:

$$n = \nu + 2 \qquad \text{(Kraemer and Thiemann, 1987).}$$

From the above results and Kraemer et al's 'Master Table', the present study found that for an effect size of $\rho = 0.55$ and a random sample of 19 or more bivariate data, a one-tail 0.05 or a two-tail 0.10 significance-level test on t_a has a power of 80% or more. For a smaller random sample of 16 data or more under the same conditions, the tests exhibit a power of 70% or more.

4.1.8 The Kendall rank correlation co-efficient (τ)

The Kendall rank correlation co-efficient (τ) measures the *association* between the data in a bivariate population. In one way, this differs from the *linear (Pearson) correlation coefficient* in that only the ranks of the data, not their actual values, are of significance. If two data pairs (x_1, y_1) and (x_2, y_2) are chosen at random from the population (X, Y), they are said to be *concordant* if $x_1 > x_2$ when $y_1 > y_2$. Conversely, if $x_1 > x_2$ when $y_1 < y_2$ or vice versa, they are said to be *discordant*. τ then is defined as the probability that two data pairs drawn at random from the population are concordant *less* the probability that they are discordant, giving:

$$\tau = P(\text{random pair concordant}) - P(\text{random pair discordant}) \qquad [A]$$

Provided ties are absent (that is, that for any pair of points, $x_1 \neq x_2$ AND $y_1 \neq y_2$), one can calculate from τ the probabilities P(random pair concordant) and P(random pair discordant), based on the assumption that:

$$P(\text{random pair concordant}) + P(\text{random pair discordant}) = 1 \qquad [B].$$

From this,

$$P(\text{random pair concordant}) = 1 - P(\text{random pair discordant}) \qquad [C]$$

and $$P(\text{random pair discordant}) = 1 - P(\text{random pair concordant}) \qquad [D].$$

By substituting [C] into [A], it follows that:

$$\tau = P(\text{random pair concordant}) - (1 - P(\text{random pair concordant}))$$

$$\Rightarrow \tau = 2P(\text{random pair concordant}) - 1$$

$$\Rightarrow \mathbf{P(\text{random pair concordant}) = \frac{(1+\tau)}{2}} \qquad [E].$$

Similarly, by substituting [D] into [A]:

$$\mathbf{P(\text{random pair discordant}) = \frac{(1-\tau)}{2}} \qquad [F].$$

τ ranges from -l (for 100% discordance) to +1 (for 100% concordance), while the value 0 denotes independence (Liebetrau, 1983). Hawkins and Weber (1980) suggest a preference for τ as opposed to other measures of association (such as the Spearman rank correlation coefficient) on the grounds of τ's mathematical tractability and smoother distribution, which better approximates the normal distribution. Liebetrau (1983) notes that τ is more easily interpreted than is the Spearman statistic. The enduring use of Kendall's τ is confirmed in the *Electronic Statistics Textbook* by StatSoft, Inc. (2004). This notes that the sample statistic can also be referred to as Kendall's τ, although the latter is properly the *population parameter*, for which the *sample statistic*, t, is the unbiased estimator (Kendall, 1970).

Ties occur when, for two randomly drawn data pairs (x_1, y_1) and (x_2, y_2), either $x_1 = x_2$ or $y_1 = y_2$ or both. In such cases, formula [B] no longer holds in its simple form since a third category of pairs of points, tie cases, enter the arena. [B] then becomes:

$$P(\text{random pair concordant}) + P(\text{random pair discordant}) + P(\text{random pair exhibits ties}) = 1 \quad [G]$$

As the satisfaction statistic, S, used in this study is an integer, has a maximum of 40 (see Chapter 4, Section 4.3.6) and is designed only rarely to drop below zero, samples of S larger than 41 were expected to contain ties. This study investigated several cases of S where the sample size indeed exceeded 41, so ties were bound to occur. Ties have to be accounted for in one of two ways, corresponding to one of two possible situations. These situations are (Kendall, 1970, and StatSoft Inc., 2004), a measure of association between a *subjective* assessment and a *known, objective order* (case (a)), and a measure of association between *two subjective assessments* (case (b)). Ties in a case (a) situation do not represent agreement, whilst in a case (b) situation they do (Liebetrau, 1983). Depending on the choice, two corresponding population parameters, τ_a and τ_b can be calculated, where $|\tau_a| \leq |\tau_b|$. These are estimated by the corresponding sample statistics t_a and t_b, defined similarly. This study selected to use t_a, since the KAI, with its high validity and reliability (see Section 2.2.4, 2.2.4.1 of Chapter 2) was considered to be close to an objective measure. Additionally, KAI-scores were determined in advance of the S-Scores, making them something of an objective order known in advance of the S-Scores.

To give a sense of what the effect of ties is on the value of τ_a, this study submits the following small population of five points:

A(1, 5), B(2, 4), C(3, 6), D(4, 6), and E(5,6).

The points may be paired in 10 ways as follows:

AB(discordant); AC(concordant); AD(concordant); AE(concordant);

BC(concordant); BD(concordant); BE(concordant);

CD(y-values tie); CE(y-values tie); and

DE(y-values tie).

The above population exhibits 1 discordant, 6 concordant and 3 tying pairs of points. Hence 10% of the pairs are discordant, 60% are concordant and the remaining 30% exhibit ties. Then:

$$\begin{aligned}\tau_a &= P(\text{random pair concordant}) - P(\text{random pair discordant}) \text{ (from [A])}\\ &= 0.6 - 0.1\\ &= 0.5.\end{aligned}$$

However, in this case only 60% of the pairs of points are concordant. For a case (a) value of $\tau > 0$, which will only count values which are definitely concordant as opposed to either tied or discordant, this may be interpreted as a weak result (see Table 40). The result could have been weaker still had the population exhibited no discordant, 50% concordant and 50% tying pairs. For example, consider the population:

A(1, 1), B(2, 2), C(3, 2), D(3, 2), and E(3, 3).

The points may be paired in 10 ways as follows:

AB(concordant); AC(concordant); AD(concordant); AE(concordant);

BC(y-values tie); BD(y-values tie); BE(concordant);

CD(both x- and y-values tie); CE(x-values tie); and

DE(x-values tie).

Then:

$$\begin{aligned}\tau_a &= P(\text{random pair concordant}) - P(\text{random pair discordant}) \text{ (from [A])}\\ &= 0.5 - 0.0\\ &= 0.5,\end{aligned}$$

so τ_a still has a value of 0.5, but only 50% of the pairs are concordant.

These examples illustrate another characteristic of τ_a:

For $\tau_a > 0$, τ_a is the minimum proportion of ***concordant*** pairs in the population, as opposed to other types of pairs.

Conversly, for $\tau_a < 0$, $-\tau_a$ is the minimum proportion of ***discordant*** pairs in the population, as opposed to other types of pairs.

If no ties occur in the data, then Formulae [E] and [F] above are valid, and provide the *maximum* number of concordant or discordant pairs in the population, respectively. Hence for $\tau_a > 0$:

$\tau_a \le$ proportion of concordant pairs of points $\le (1 + \tau_a)/2$ (from [E] above),

and for $\tau_a < 0$:

$-\tau_a \le$ proportion of discordant pairs of points $\le (1 - \tau_a)/2$ (from [F] above).

Using these results, values of τ_a can be given meaning, as tabulated in Table 41 (below) for various values of $\tau_a > 0$.

<u>Table 41</u>: Interpretation of Kendall's τ_a values as the probabilities of the corresponding Concordances and Discordances in a bivariate population

τ_a: Selected Values	Minimum Concordance	Maximum Concordance	Comment on the size of τ_a
1.0000	100%	100%	High values. Minimum concordances above 50%. Maximum concordance 80% or more.
0.9000	90%	95%	
0.8000	80%	90%	
0.7000	70%	85%	
0.6000	60%	80%	
0.5000	50%	75%	Intermediate value. Minimum can be as low as 50%.
0.4000	40%	70%	Low values. Minimum concordances can be below 50%.
0.3000	30%	65%	
0.2000	20%	60%	
0.1000	10%	55%	Very low values. Highest concordance < 60%.
0.0000	0%	50%	

From Table 41 it is evident that $\tau_a = 0.5$ is the lowest positive value which could espouse a concordance case of 50%. In the context in which $\tau_a > 0$ is calculated, where ties are considered immaterial, this would be rated as weak a result as that of independence. Any higher value of τ_a would mean a guaranteed higher minimum concordance than 50%. Values for $\tau_a > 0.5$ were consequently rated as "high" by this study. For τ_a in the range $0.2 \leq \tau_a \leq 0.4$, the minimum concordances may be lower than 50%, so such values were rated as "low". This study thus set $\tau_a = 0.5$ as a "medium" or intermediate value. Values of τ_a such that $0 < \tau_a < 0.2$, with maximum possible concordances which are less than 60%, this study considered to be too low to be of material value, even if they proved to be statistically significant.

By symmetry, a set of complementary values was assumed for $\tau_a < 0$, with $-0.4 \leq \tau_a \leq -0.2$ representing a "low" departure, $\tau_a = -0.5$ a "medium" departure, and $\tau_a < -0.5$ a "high" departure from independence.

Parallel results hold for the corresponding sample statistics, t_a and t_b.

4.1.8.1 Formulae for testing the significance of associations measured as t_a

Kendall (1970) showed that for sample sizes of $n \geq 10$, methods based on a normal distribution transformation of t_a can be used for testing its significance. The formulae for the variances and standard normal statistics required to carry out such tests are given below. These formulae hold only for the null hypothesis (Liebetrau, 1983), and as previously discussed, this is entirely satisfactory so long as rejection of the null hypothesis is both sought and successful. It should be noted that the same formula holds whether t_a or t_b is used as the measure of association.

Kendall (1970) gives the formula for τ for a population with untied data as:

$$\tau = \frac{2S'}{N(N - 1)}$$

where S′ = number of concordant data pairs - the number of discordant data pairs

and N = population size.

Note: S′ has been used to distinguish this statistic from the satisfaction statistic, S.

The same formula can be applied to samples of size n to obtain the corresponding sample statistic, t_a, where ties do not contribute to concordance. This is:

$$t_a = \frac{2s'}{n(n - 1)}. \qquad \text{(Kendall, 1970)}$$

As with the Pearson correlation coefficient, the significance of t_a is based on a model espousing a null hypothesis of independence in the population, thus:

H_0: $\tau_a = 0$

H_a: $\tau_a \neq 0$, or $\tau_a > 0$, or $\tau_a < 0$.

The formulae required to test the significance of t_a is given by Kendall (1970) and Liebetrau (1983) as follows:

$$\sigma^2(s') = {}^1/_{18}\,[n(n-1)(2n+5) - A' - B'] + \frac{A\,B}{9n(n-1)(n-2)} + \frac{2\,U\,V}{n(n-1)}.$$

Where: n = sample size, u = number of consecutive ties in the first ranking,

v = number of consecutive ties in the second ranking,

$$A = \sum_u u(u-1)(u-2)$$

$$B = \sum_v v(v-1)(v-2)$$

$$A' = \sum_u u(u-1)(2u+5)$$

$$B' = \sum_v v(v-1)(2v+5)$$

$$U = \tfrac{1}{2}\sum_u u(u-1) \qquad \text{and}$$

$$V = \tfrac{1}{2}\sum_v v(v-1)$$

Hence: $\sigma^2(t_a) = \sigma^2(s') / ({}_nC_2)^2$

Consequently the test statistic for t_a can be calculated as:

$$z(t_a) = t_a / \sigma(t_a) = s' / \sigma(s')$$

If the null hypothesis of independence is to be tested using the standard normal (z) distribution, the z-statistic needs to be computed for t_a from the above formula, so that the tail area can be determined using tables.

4.1.8.2 Formulae for testing the powers of significance-level tests on t_a

Kraemer and Thiemann (1987) give formulae and tables for the power of significance level tests on t_a. These require their *critical effect size index* (Δ). For determining the latter, they give the formula:

$$\Delta = 2\,[\arcsin(\tau) - \arcsin(\tau_0)] / \pi .$$

If $\tau_0 = 0$, signifying independence, the formula reduces to:

$$\Delta = 2 \arcsin(\tau) / \pi .$$

This study assumed an effect size of $\tau = 0.5$ in the light of the discussion in Section 4.1.8.1 (above) which rated this as the only "medium" value for τ. This gives the required value for Δ as: $\Delta = 2 \arcsin(\tau) / \pi = 2 \arcsin(0.5) / \pi = 0.3333$.

Δ and the desired power are then applied to Kraemer et al's (1987) 'Master Table'. This yields a parameter ν, which is related to sample size n (in this case) by:

$$n = 0.437\,\nu + 4 \qquad \text{(Kraemer and Thiemann, 1987).}$$

From the above results and Kraemer et al's 'Master Table', the present study found that for an effect size of $\tau_a = 0.5$ and a random sample of 28 or more bivariate data, a one-tail 0.05 significance-level test on t_a has a power of 80% or more. For a smaller random sample of 23 data or more under the same conditions, the 0.05 significance-level test exhibits a power of 70% or more.

4.1.9 The Mann-Whitney Test for a difference in sample location

Strictly speaking, this is a test for a significant difference in sample *medians*, but if the distributions are known to be symmetric (though not necessarily normal), then it also is a test for the difference of means. As with the t-test for a difference between means described in Section 4.1.11 below, an assumption is made that the two populations are independent, and that the data collected should not exhibit corresponding values in the samples. The test is only valid for two samples of S, therefore, where no user-system (US) contributes S-data to them both (Zar, 1999). The method outlined here is as described by Zar (1999), with some input from Steffens and Strydom (2004), Lind, Marchal and Mason, (2002), Cohen (1988) and Kraemer and Thiemann (1987).

The data in both samples are pooled and ranked where the smallest datum in both samples is given the rank of 1. If data tie, the mean rank is given to each. After this, the samples are separated out and the ranks for each sample are summed, to give values R_1 and R_2. For a one-tail test, the U-statistic is then calculated using either of the formulae:

$$U = n_1n_2 + n_1(n_1 + 1)/2 - R_1$$

$$U' = n_2n_1 + n_2(n_2 + 1)/2 - R_2$$

Where n_1, n_2 are the sizes of each sample, and

R_1, R_2 are the respective sums of the ranks of each sample (Zar, 1999).

The statistics U or U′ can be compared to critical values given in tables for various sample sizes, such as those supplied by Zar (1999). For a two-tail test, both U and U′ need to be calculated.

For samples where the smaller exceeds a size of 20 or the larger exceeds 40, a normal approximation is required. This is:

$$Z = (U - \mu_U) / \sigma_U$$

where $\mu_U = n_1n_2 / 2$ and $\sigma_U = \sqrt{n_1n_2 (n_1 + n_2)/12}$ (Zar, 1999)

No formal power methods were found specifically for this test. However, Kraemer and Thiemann (1987) suggest that the power method for the difference of means given in Section 4.1.11 should be used as the above test exhibits only slightly less power.

4.1.10 Fitting curves to a time series

Four references have been used to compile this section; Prins (2005), Hyams (2003), Zar (1999) and Berenson & Levine (1986).

Prins (2005) defines a time series as,

> "An ordered sequence of values of a variable at equally spaced time intervals."

He notes further that time series occur frequently in the study of industrial data, the application of time series analysis being two-fold: to understand the underlying forces and structure that produced the observed data, and to fit a model to the data, thereby allowing forecasting and monitoring of a given process (Prins, 2005). He explains that data can be smoothed by way of a number of techniques including the "moving averages" method. This weights past consecutive observations equally.

Berenson and Levine (1986) recommend that the value of n be odd. This is so there is an unambiguous middle time-value, which can be used as the time coordinate. If, for example, data for consecutive days over a period of a month are to be averaged, a feasible choice would be 31 days, making the sixteenth reading the time coordinate. The same authors give the four components of a time series as

- Trend (T) (or secular trend) (general upward or downward movement);
- Seasonal variation (S) (periodic fluctuations with the seasons);
- Cyclical variation (C) (periodic fluctuations not seasonally based); and
- Random variation (R) (other unexplained variation).

They also give the formula for value y_i at time i, as:

$$y_i = T_i \times S_i \times C_i \times R_i$$

In terms of curves to be fit to time series data, Hyams (2003) notes that polynomials tend to give "decent curve fits" to almost any data set, but higher order polynomials (as a rule of thumb, over 9) tend to oscillate badly. Of further significance he observes that higher order polynomials offer no insight into the model that governs the data (Hyams, 2003).

Curve-fitting for the two simplest polynomial cases, namely, the straight line with a polynomial order of 1 and the quadratic function with an order of 2 are explored as potential models in Appendix 3.2. Zar (1999) gives a procedure of obtaining the best-fitting linear function of order 0 or 1 as a first step. One then tests the best-fitting polynomials of progressively higher degree until one reaches one that does not provide a significantly better fit than the previous one. The test statistic for each iteration of this process is an F-statistic with the following formula:

$$F = \frac{\text{(regression sum of squares for higher degree model) - (regression sum of squares for lower degree model)}}{\text{residual mean square for higher degree model}}$$

for which the numerator degrees of freedom are taken as 1 and the denominator degrees of freedom are the residual degrees of freedom of the higher degree model and the sample size less 2 (Zar, 1999). The calculated F-statistic can then be compared against critical values in tables to test the hypothesis:

H_0: Higher degree polynomial ***is not*** a better fit, against

H_a: Higher degree polynomial ***is*** a better fit

Zar (1999) notes that after finding the lowest-degree polynomial which *cannot* be justified as a significantly better fit that the previous one, one may test at least the next higher degree, best-fitting polynomial, so that significant terms of higher powers are not inadvertently neglected. However, he gives a counterbalancing argument; the possible error of multicollinearity for the fitting of polynomials of degrees higher than 2. This arises because the independent variables (x-values) will be correlated with their powers. The present study took the option of testing up to, but not exceeding, best-fitting polynomials of the third degree in situations where the curve-fitting of polynomial functions was appropriate.

4.1.11 t-test for a difference between independent population means where the population variances are not assumed to be equal

Bartlein (2005) gives a procedure to test for a difference in population means based on a sample of data drawn from each population. This test does not assume the equality of the population variances, but it *does* assume that the populations are independent. As with the Mann-Whitney test described above in Section 4.1.9, differences between sample means of S-Scores would only be valid if no US contributes S-data to both samples. Zar (1999) notes that this test is quite robust even when the data are skew, hence the second assumption of population normality is of no great importance.

For means μ_1 and μ_2 from each population, the research model is:

H_0: $\mu_1 - \mu_2 = 0$

H_a: $\mu_1 - \mu_2 > 0$; $\mu_1 - \mu_2 < 0$ (one-tail tests); or $\mu_1 - \mu_2 \neq 0$ (two-tail test)

The test statistic is:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s_1^2/n_1 + s_2^2/n_2}}$$

where $\bar{x}_1$ and $\bar{x}_2$ are the respective sample means and s_1 and s_2 the sample standard deviations.

The number of degrees of freedom(ν) of t are given by:

$$\nu = [s_1^2/n_1 + s_2^2/n_2\,] \,/ \left[\frac{s_1^2/n_1}{n_1 - 1} + \frac{s_2^2/n_2}{n_2 - 1}\right]$$

This method is cited in other references such as Berenson and Levine (1986) and Hawkins and Weber (1980). However, they differ in the formula for determining the degrees of freedom. After testing all three alternatives, this study found Bartlein's to give the lowest degrees of freedom in most cases, thus yielding the strictest significance level test. It was thus the formula for the degrees of freedom adopted.

To determine the power of a test which detects no difference in means, one requires the effect size index (d). The formula for d is given by Cohen (1988) for populations of unequal size and unequal variance as:

$$d = (\mu_1 - \mu_2) / \sigma_{pooled} \text{ (one-tailed), or } d = |\mu_1 - \mu_2| / \sigma_{pooled} \text{ (two-tailed),}$$

where μ_1 and μ_2 are the means of the two populations and σ_{pooled} is their pooled standard deviation (see Section 4.1.2.2 for a discussion of power testing).

σ_{pooled} is calculated from the respective population variances σ_1^2 and σ_2^2 using:

$$\sigma_{pooled} = \sqrt{(\sigma_1^2 + \sigma_2^2)/2}$$

The power of a test can be looked up in tables supplied by Cohen (1988), given the significance level, α, the effect size index d, and n, a composite of the two sample sizes, n_1 and n_2. n may be calculated using:

$$n = 2n_1 n_2 / (n_1 + n_2) \qquad \text{(Cohen, 1988)}$$

Cohen (1988) describes values for d of 0.2, 0.5 and 0.8 as *small*, *medium* and *large*, respectively.

4.1.12 A test for the difference between population variances

Zar (1999) gives a ratio test for the significant differences between population variances based on the ratio of the sample variances. The statistic

$$F = s_1^2 / s_2^2$$

is calculated, with $s_1^2 \geq s_2^2$, so that $F \geq 1$, where s_1^2 and s_2^2 are the respective sample variances. Zar gives tables of critical values of the F-statistic for *pairs* of degrees of freedom, one associated with each sample. If each member of the pair has size m and n respectively, then the corresponding degrees of freedom are $m - 1$ and $n - 1$. As with the difference-between-means test, assumptions of population normality and independence are made. The acceptance or rejection of the null hypothesis $s_1^2 = s_2^2$ can then be determined from tables of F for various significance levels.

As far as the power of such tests is concerned, Kraemer and Thiemann (1987) give the necessary formulae and tables. Their recommended formula for the *critical effect size index* (Δ) is:

$$\Delta = (\sigma_1^2 - \sigma_2^2) / (\sigma_1^2 + \sigma_2^2).$$

Δ and the desired power are then applied to Kraemer et al's (1987) 'Master Table'. This yields a parameter ν, which is related to the recommended sample size n′ (in this case) by:

$$n' = [(\nu + 3) + [(\nu + 3)^3 - 16pq(\nu + 2)]^{1/2}]/4pq$$

where $p = m/(m + n)$ and $q = n/(m + n)$. (Kraemer and Thiemann, 1987).

If the sample sizes are equal, then:

$$n' = 2\nu + 4 .$$

4.1.13 Hypotheses on the slope (β) of a linear regression line

These hypotheses aim to test whether or not a linear regression line has a non-zero slope, which then signifies the presence of a linear relationship in bivariate data (Zar, 1999). The model is:

H_0: $\beta = 0$

H_a: $\beta \neq 0$

The test-statistic, Student's t, is calculated using the formula:

$t = b/S_b$

where b is the slope of the best-fitting sample regression line, and S_b is given by

S_b = Residual mean square / Σx^2

The *residual mean square* is based on the *residual sum of squares*. Given a scatter-gram of points, each with an x and a y coordinate, to which a regression has been fitted, then associated with each point is a true y-value as opposed to its *estimate* based on the regression line. The associated *residual* is the difference of the two y-values. Regression lines, fitted by the method of *least squares* are positioned so that the *residual sum of the squares* is a minimum. The *residual mean square* (Residual MS) is the *residual sum of squares* (Residual SS) averaged over the degrees of freedom for the regression. In the case of many regressions, this is the sample size less 2.

So long as the sample is drawn randomly from a bivariate normal population, powers of tests on β correspond exactly to those for the corresponding correlation coefficient, ρ. The first step is thus to estimate an effect size for ρ. Then Kraemer and Thiemann's (1987) formulae and tables cited in Section 4.1.7 may be employed. For *critical effect size index* (Δ) they give:

$$\Delta = \rho,$$

and for recommended sample size n they suggest:

$$n = \nu + 2 .$$

(Kraemer and Thiemann, 1987)

Appendix 4.2

Combined satisfaction/dissatisfaction instrument

System Name: ....

Organization: ....

Please enumerate all the *positive aspects* which you or others find with the system, then rate the *importance* of each on the seven-point scale provided.

Please be guided by the following descriptions:

(7)	(6)	(5)	(4)	(3)	(2)	(1)
extremely important	*very important*	*important*	*rather important*	*of some significance*	*slight*	*barely worth mentioning*

	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)

Please enumerate all the *negative aspects* which you or others find with the system, then rate the *importance* of each on the seven-point scale provided.

Please be guided by the following descriptions:

(7)	(6)	(5)	(4)	(3)	(2)	(1)
an extremely serious/totally insoluble problem	*a very serious problem*	*a serious problem*	*a rather serious problem*	*a significant problem*	*a slight problem*	*no real problem*

	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)
	(7) (6) (5) (4) (3) (2) (1)

Appendix 4.3

Program to calculate Kendall-t_a values and their significance

(Written in True BASIC © by the author)

For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). For the verification of the Kendall-t calculations and their associated standard normal (z) distribution, see Appendix 4.4.

```
PROGRAM DetermineKendallAssociations
dim X(100), XRank(100), Y(100), YRank(100)
dim InVar(100), TempVar(100), TempRank(100), Rank(100)
```

Program lines (first optional set) incorporated for the pilot study, Chapter 4, Section 4.3.3

```
let n = 64 != number of bivariate pairs
let Max = 4 != number of hypotheses to be tested

!HYPOTHESES
data "R-Score on UIS"
!R-score proper: Total intensity of complaints
data 29,8,26,4,2,18,6,7,18,16
data 16,0,9,24,13,21,9,15,10,2
data 30,26,19,11,15,8,30,1,10,12
data 14,1,6,13,14,18,0,28,6,29
data 6,11,7,13,20,3,2,9,12,7
data 1,11,23,13,10,7,14,9,11,8
data 9,6,9,5

!UIS
data 15.5,17,6.5,12,3,11,14.5,13.5,4.5,-.5
data 18.5,20,30,11,7,13,8,18,6,9
data .5,-16.5,-13.5,9.5,9,9,1,15,9.5,5.5
data 8,-4.5,16,-7.5,15,20,4,5.5,6.5,6.5
data 23.5,8.5,19,13,.5,24,23,37,22,.5
data 34.5,9,15,18,1.5,6.5,12,4.5,26,15.5
data 16.5,17.5,18.5,26.5
```

```
data "UIS on CVS"
!UIS
data 15.5,17,6.5,12,3,11,14.5,13.5,4.5,-.5
data 18.5,20,30,11,7,13,8,18,6,9
data .5,-16.5,-13.5,9.5,9,9,1,15,9.5,5.5
data 8,-4.5,16,-7.5,15,20,4,5.5,6.5,6.5
data 23.5,8.5,19,13,.5,24,23,37,22,.5
data 34.5,9,15,18,1.5,6.5,12,4.5,26,15.5
data 16.5,17.5,18.5,26.5
!Satisfaction score: Initial question (CVS)
data 4,5,2,5,5,6,5,7,5,4
data 5,7,5,5,4,5,5,5,7,6
data 3,1,1,6,6,3,3,6,6,6
data 6,7,6,2,1,6,6,2,6,3
data 7,1,6,5,6,6,7,7,6,2
data 6,4,4,6,4,5,6,6,6,5
data 6,6,5,6

data "CVS on Modified R-Score"
!Satisfaction: initial question (CVS)
data 4,5,2,6,6,6,4,7,5,5
data 5,7,5,5,4,5,5,5,5,6
data 3,1,1,6,6,3,3,6,6,6
data 6,7,6,2,1,6,6,2,6,3
data 7,1,6,6,6,6,6,7,6,2
data 6,4,4,6,4,5,6,6,6,5
data 6,6,5,6
!Modified R-Score
data 33,11,32,7,5,20,9,8,21,20,19,1,12,27,17,24
data 12,18,11,4,35,33,26,13,17,13,35,3,12,14,16,2
data 8,19,21,20,2,34,8,34,7,18,9,16,22,5,3,10,14
data 13,3,15,27,15,14,10,16,11,13,11,11,8,12,7

data "UIS on Modified R-Score"
!UIS
!Simple modification of R-Score
data 15.5,17,6.5,12,3,11,14.5,13.5,4.5,-.5
data 18.5,20,30,11,7,13,8,18,6,9
data .5,-16.5,-13.5,9.5,9,9,1,15,9.5,5.5
data 8,-4.5,16,-7.5,15,20,4,5.5,6.5,6.5
data 23.5,8.5,19,13,.5,24,23,37,22,.5
data 34.5,9,15,18,1.5,6.5,12,4.5,26,15.5
data 16.5,17.5,18.5,26.5
!Modified R-Score
data 33,11,32,7,5,20,9,8,21,20,19,1,12,27,17,24
data 12,18,11,4,35,33,26,13,17,13,35,3,12,14,16,2
data 8,19,21,20,2,34,8,34,7,18,9,16,22,5,3,10,14
data 13,3,15,27,15,14,10,16,11,13,11,11,8,12,7
```

Program lines (second optional set) incorporated for pilot study, Chapter 4, Section 4.3.7

```
let n = 20 != number of bivariate pairs
let Max = 5 != number of hypotheses to be tested

!HYPOTHESES
!**********
data "CVSvR"
!CVS
data 5,6,1,6,6,6,6,5,4,3,6,2,2,2,2,6,5,5,2,6
!R-Score
data 22,1,25,10,2,10,4,2,12,10,2,10,4,4,9,16,10,5,2,3

data "CVSvS"
!CVS
data 5,6,1,6,6,6,6,5,4,3,6,2,2,2,2,6,5,5,2,6
!S-Score
data 16,38,9,29,37,29,35,36,25,26,37,25,31,31,26,23,28,33,33,36

data "CVSvP"
!CVS
data 5,6,1,6,6,6,6,5,4,3,6,2,2,2,2,6,5,5,2,6
!Positives
data 10,29,10,20,25,24,33,19,6,14,19,16,6,4,6,19,11,13,11,7

data "CVSvCom"
!CVS
data 5,6,1,6,6,6,6,5,4,3,6,2,2,2,2,6,5,5,2,6
!CVS + Positives - R-Score
data -7,34,-14,16,29,20,35,22,-2,7,23,8,4,2,-1,9,6,13,11,10

data "RvP"
!R-Score
data 22,1,25,10,2,10,4,2,12,10,2,10,4,4,9,16,10,5,2,3
!Positives
data 10,29,10,20,25,24,33,19,6,14,19,16,6,4,6,19,11,13,11,7
```

```
!MAIN PROGRAM

clear
print "Performing correlations . . ."
open #15: name "c:\Thesis\PilotSt1.dat", create newold, organization text, access output
erase #15
!open #15: printer

set #15: margin 80
set #15: zonewidth 6

print #15,   using "<####### ": "Hypothesis", "   S", "t a", "s(ta)", "z(ta)", "t b", "s(tb)", "z(tb)"

print #15: Repeat$("-------- ", 8)


for z = 1 to Max
```

```
   call ProcessValues
next z

close #15
!END MAIN PROGRAM


SUB ProcessValues

read Hypothesis$
print #15, using "<#####   ": Hypothesis$;
for i = 1 to n
   read X(i)
next i

for i = 1 to n
   read Y(i)
next i

call KendallKernel

print #15, using "--------#": S;
print #15, using "--.####  " : Ta, TaSD, Taz, Tb, TbSD, Tbz
print #15

print "DONE."

END SUB
```

SUB **KendallKernel !see Appendix 4.4 for details**

```
call RankValsForKendall(X, XRank)
let U = TieFactorSum / 2
let A1 = FirstABFactor
let A2 = SecondABFactor

call RankValsForKendall(Y, YRank)
let V = TieFactorSum / 2
let B1 = FirstABFactor
let B2 = SecondABFactor

call DetNumerator
call KendallCalc

print
print
print
print

END SUB

SUB RankValsForKendall(InVar(), Rank())

mat TempVar = InVar

for j = n to 2 step -1
```

```
   for i = 2 to j
      if TempVar(i) > TempVar(i - 1) then
        let Temp = TempVar(i)
        let TempVar(i) = TempVar(i - 1)
        let TempVar(i - 1) = Temp
      end if
   next i
next j

let TieFactorSum = 0
let FirstABFactor, SecondABFactor = 0
mat Rank = 0

for j = 1 to n
   let Position = j
   let TieCount = 0
   for i = 1 to n
      if InVar(i) = TempVar(j) and Rank(i) = 0 then
        let TieCount = TieCount + 1
      end if
   next i
   for i = 1 to n
      if InVar(i) = TempVar(j) and Rank(i) = 0 then
         let Rank(i) = Position + TieCount/2 -1/2
      end if
   next i
   let TieFactorSum = TieFactorSum + TieCount*(TieCount - 1)
   let FirstABFactor = FirstABFactor +
              TieCount*(TieCount - 1)*(TieCount - 2)
   let SecondABFactor = SecondABFactor +
              ieCount*(TieCount - 1)*(2*TieCount + 5)

   let j = j + TieCount - 1
next j

END SUB


SUB DetNumerator

let S = 0

for j = 1 to n - 1
   for i = j + 1 to n

      if XRank(i) > XRank(j) then
        let XMultiplier = 1
      else if XRank(i) < XRank(j) then
        let XMultiplier = -1
      else
        let XMultiplier = 0
      end if

      if YRank(i) > YRank(j) then
        let YMultiplier = 1
      else if YRank(i) < YRank(j) then
        let YMultiplier = -1
```

```
        else
           let YMultiplier = 0
        end if

        let S = S + XMultiplier * YMultiplier

    next i
next j

END SUB


SUB KendallCalc

let SVar = ((n*n - n)*(2*n + 5) - A2 - B2)/18  +  A1*B1 / ((9*n*n - 9*n)*(n - 2))  +  2*U*V / (n*n
               - n)
let Ta = 2*S/(n*n - n)
let TaVar = 4*SVar / (n*n - n)^2
let TaSD = Sqr(TaVar)
let Taz = Ta / TaSD

let Tb = S / Sqr(n*n/2 - n/2 - U) / Sqr(n*n/2 - n/2 - V)
let TbVar = SVar / (n*n/2 - n/2 - U) / (n*n/2 - n/2 - V)
let TbSD = Sqr(TbVar)
let Tbz = Tb / TbSD

END SUB


END PROGRAM
```

Appendix 4.4

Verification of the Kendall-t program kernel

(which calculates Kendall-t_a values and the associated z-statistics, from which their significances can be determined)

The program given in Appendix 4.3 was verified by testing the compliance of its calculating kernel against results from the SPSS® statistical package. The program given below, which contains the same kernel (called KendallKernal), also contains five sets of test data. The output from this program was then compared to the output from the same five sets of data obtained from the SPSS® package. Descriptions of each test sample are given in Table 42. The comparative results are given in Table 43.

Table 42: Descriptions of samples used in the compliance test of the program kernel which calculates Kendall-t values

Sample Number	Compliance Sample Description
1	The first set of bivariate data given in program Appendix 4.3 (see data statements at the end of the program).
2	Data set up so that X increases consistently with Y, giving a test of the extreme, t = +1 (see data statements at end of the program given below).
3	Data set up so that X decreases with Y, giving a test of the extreme, t = -1 (see data statements at end of the program given below).
4	Data set up so that X has five optional values only to test that kernel can handle tie cases (see data statements at end of the program given below).
5	Data set up with randomly selected Y on randomly selected X (ten cases only) to test for tie-handling and for t ≈ 0 (see data statements at end of the program given below).

Table 43: Table of comparative values: Program kernel versus the SPSS® Statistics Package

	Values Computed By:						
	The kernel of the software developed for this study, which calculates Kendall-t_a and – t_b values, with z-statistics					The SPSS® Statistics Package	
Sample*	t_a	$z_{(ta)}$	t_b	$z_{(tb)}$	Significance (1-tail)**	Kendall tau-b	Significance (1-tail)
1	-0.0714	-0.8236	-0.0740	-0.8236	0.206	-0.074	0.205
2	1.0000	11.4861	1.0000	11.4861	0.000	1.000	0.000
3	-1.0000	-11.4861	-1.0000	-11.4861	0.000	-1.000	0.000
4	0.8128	9.5451	0.9016	9.5451	0.000	0.902	0.000
5	-0.0915	-1.0601	-0.0972	-1.0601	0.145	-0.097	0.145
* size = 62 in all cases		** Read from standard normal distribution tables using either $z_{(ta)}$ or $z_{(tb)}$.					

Brace, Kemp and Snelgar (2000) confirm that the SPSS® Statistics Package only determines Kendall tau-b and tau-c. This study used t_a (or as some would call it, tau-a) (see Chapter 4, Section 4.1). However, the values for t_b and tau-b (pink) agree, as do the values for their corresponding significances, very nearly (green). This verifies the values of t_b and $z(t_b)$ as produced by the program kernel. According to Kendall (1970) and Liebetrau (1983), the significances of t_a and t_b determined from the same data set are the same. The z-values calculated from the original t_a and t_b data agree (yellow), showing compliance with this requirement. However the $z(t_a)$ are calculated from the same s' value as for t_a, supporting the assertion that the **t_a are correctly determined**, and that the corresponding **$z(t_a)$ values for finding their significances are correctly calculated in all five cases**.

4.4.1 Program and test data

(For a full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997))

```
PROGRAM ToTestKendallKernel

!Define variables and parameters
dim X(100), XRank(100), Y(100), YRank(100)
dim InVar(100), TempVar(100), TempRank(100), Rank(100)

let n = 62 != number of bivariate pairs
!let Max = 1 != number of hypotheses to be tested

!MAIN PROGRAM: TEST SHELL FOR KENDALL KERNEL

clear
print "Performing correlations . . ."
open #15: name "e:KKndTest.txt", create newold, organization text, access output
erase #15

set #15: margin 120
set #15: zonewidth 10

print #15: "   S ", "   ta ", "   s(ta) ", "   z(ta) ", "   tb ", "   s(tb) ", "   z(tb)"

call KendallKernel !The Kendall Kernel under test is called from here.
                   !It prints out the results as a text file.

close #15

print "Done."
get key: Key

!END MAIN PROGRAM
```

Program Kernel to Calculate Kendall-t values and the associated standard-normal statistics

```
SUB KendallKernel

!Read in bivariate test-data
for i = 1 to n
   read X(i)
next i
for i = 1 to n
   read Y(i)
next i


call Kendall                    !Call sub-program for main calculation


!Print output data
print #15: Using$("----#", S),
print #15: Using$("--.####", Ta),
print #15: Using$("--.####", TaSD),
print #15: Using$("---.####", Taz),
print #15: Using$("--.####", Tb),
print #15: Using$("--.####", TbSD),
print #15: Using$("---.####", Tbz)

END SUB


SUB Kendall

call RankValsForKendall(X, XRank)
let U = TieFactorSum / 2
let A1 = FirstABFactor
let A2 = SecondABFactor

call RankValsForKendall(Y, YRank)
let V = TieFactorSum / 2
let B1 = FirstABFactor
let B2 = SecondABFactor

call DetNumerator
call KendallCalc

print
print
print
print

END SUB
```

SUB RankValsForKendall(InVar(), Rank())

```
mat TempVar = InVar

for j = n to 2 step -1
   for i = 2 to j
      if TempVar(i) > TempVar(i - 1) then
        let Temp = TempVar(i)
        let TempVar(i) = TempVar(i - 1)
        let TempVar(i - 1) = Temp
      end if
   next i
next j

let TieFactorSum = 0
let FirstABFactor, SecondABFactor = 0
mat Rank = 0

for j = 1 to n
   let Position = j
   let TieCount = 0
   for i = 1 to n
      if InVar(i) = TempVar(j) and Rank(i) = 0 then
        let TieCount = TieCount + 1
      end if
   next i
   for i = 1 to n
      if InVar(i) = TempVar(j) and Rank(i) = 0 then
         let Rank(i) = Position + TieCount/2 -1/2
      end if
   next i

 let TieFactorSum = TieFactorSum + TieCount*(TieCount - 1)
   let FirstABFactor = FirstABFactor +
         TieCount*(TieCount - 1)*(TieCount - 2)
   let SecondABFactor = SecondABFactor +
         TieCount*(TieCount - 1)*(2*TieCount + 5)

   let j = j + TieCount - 1
next j
```

END SUB

SUB DetNumerator

```
let S = 0
for j = 1 to n - 1
   for i = j + 1 to n
      if XRank(i) > XRank(j) then
        let XMultiplier = 1
      else if XRank(i) < XRank(j) then
        let XMultiplier = -1
      else
        let XMultiplier = 0
      end if
      if YRank(i) > YRank(j) then
```

```
      let YMultiplier = 1
    else if YRank(i) < YRank(j) then
      let YMultiplier = -1
    else
      let YMultiplier = 0
    end if

    let S = S + XMultiplier * YMultiplier
  next i
next j
```

END SUB

SUB KendallCalc

```
let SVar = ((n*n - n)*(2*n + 5) - A2 - B2)/18  +  A1*B1 / ((9*n*n - 9*n)*(n - 2))  +  2*U*V / (n*n
- n)
let Ta = 2*S/(n*n - n)
let TaVar = 4*SVar / (n*n - n)^2
let TaSD = Sqr(TaVar)
let Taz = Ta / TaSD

let Tb = S / Sqr(n*n/2 - n/2 - U) / Sqr(n*n/2 - n/2 - V)
let TbVar = SVar / (n*n/2 - n/2 - U) / (n*n/2 - n/2 - V)
let TbSD = Sqr(TbVar)
let Tbz = Tb / TbSD
```

END SUB

!COMPLIANCE TEST DATA
!******** **** ****`**
!The active test sample needs to have the comment marks (!) in front of the correlative Data statements removed

! Sample 1: t_b = -0.7400 from output of Appendix 4.3

```
!Y
!Data
1,1,1,2,2,3,3,3,4,5,5,5,6,7,8,8,9,10,12,12,12,12,12,12,12,12,13,14,14,15,15,16,16,16,16
!Data 16,18,19,20,20,22,22,22,23,23,25,26,27,28,29,31,31,34,34,36,36,36,39,39,40,42,74

!X
!Data 25,-1,30,33,37,24,13.50,32,23,0,36,30,26,0,35,31,29,31,30,21,31,10,29,39,31,31,23
!Data 32,38, 30,35,9,27,20,18,38,-1,25,32,36,15,34,26,-12,37,14,18,32,31,38,21,12,31,25
!Data 26,30,26,22,31,30,13,-3
```

!Sample 2: t_b = 1.0000 expected

```
!Y
!Data -31,-30,-29,-28,-27,-26,-25,-24,-23,-22,-21,-20,-19,-18,-17,-16,-15,-14,-13,-12,-11,-10
!Data -9,-8,-7,-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23
!Data 24,25,26,27,28,29,30

!X
!Data 2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32,34,36,38,40,42,44,46,48,50,52,54,56,58
!Data 60,62,64,66,68,70,72,74,76,78,80,82,84,86,88,90,92,94,96,98,100,102,104,106,108
!Data 110, 112,114,116,118,120,122,124
```

!Sample 3: t_b = -1.0000 expected
!Y
!Data -31,-30,-29,-28,-27,-26,-25,-24,-23,-22,-21,-20,-19,-18,-17,-16,-15,-14,-13,-12,-11,-10
!Data -9,-8,-7,-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23
!Data 24,25,26,27,28,29,30

!X
!Data -2,-4,-6,-8,-10,-12,-14,-16,-18,-20,-22,-24,-26,-28,-30,-32,-34,-36,-38,-40,-42,-44,-46
!Data -48,-50,-52,-54,-56,-58,-60,-62,-64,-66,-68,-70,-72,-74,-76,-78,-80,-82,-84,-86,-88,-90
!Data -92,-94,-96,-98,-100,-102,-104,-106,-108,-110,-112,-114,-116,-118,-120,-122,-124

!**Sample 4: t_b = 1.000 expected (Heavy tying in the data)**
!Y
!Data -31,-30,-29,-28,-27,-26,-25,-24,-23,-22,-21,-20,-19,-18,-17,-16,-15,-14,-13,-12,-11,-10
!Data -9,-8,-7,-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22
!Data 23,24,25,26,27,28,29,30

!X
!Data 1,1,1,1,1,1,1,1,1,1,1,1,2,2,2,2,2,2,2,2,2,2,2,2,3,3,3,3,3,3,3,3,3,3,3,3,4,4,4,4,4,4,4,4,4
!Data 4,4,4,5,5,5,5,5,5,5,5,5,5,5,5,5

!Sample 5: t_b = 0.000 expected (tying in the data). Data are random.
!Y
Data 15,9,41,74,0,72,67,55,71,35,41,96,20,45,38,1,67,63,39,55,29,78,70,6,78,76,47,46,93
Data 12,55,49,18,70,35,97,55,45,84,18,18,18,67,20,72,34,54,30,22,48,74,76,2,7,64,95,23
Data 91,48,55,91,40

!X
Data 8,7,0,1,5,4,5,0,5,9,8,8,1,3,1,5,9,0,4,4,1,2,4,5,2,5,2,6,2,4,6,8,5,1,6,1,3,8,6,5,3,4,3,4,6
Data 0,4,9,2,2,0,4,7,1,0,7,4,4,3,2,3,1

END PROGRAM

Appendix 5.1

Program to produce regression of S on time (see Chapter 5, Figure 5)

This program plots a scatter gram of S against time in days, for all the S-Score readings actually taken and then adds the best-fitting linear regression line. The output is recovered from the screen by taking a screen shot. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements (see End of program).

```
PROGRAM ProduceScattergramOfS-ScoresOnTime
!Draw coordinates
set window -120, 870, -20, 80
set back "white"
set color "red"

!Draw horizontal axis
plot lines: -120, 0; 870, 0
for i = -90 to 870 step 90
   plot lines: i, 0; i, .5
next i

!Draw vertical axis
plot lines: 0, -20; 0, 50
for i = -20 to 50 step 10
   plot lines: 0, i; 5, i
next i

!To create table of day, S values
open #15: name "e:SOnDays.csv", create newold, organization text, access output
erase #15
set #15: Margin 128

!Variables set to check for domain and range
let MinS = 100
let MaxS = -100
let FirstDay = 1000
let LastDay = -1000

!Read and plot S-Score readings on Days
set color "green"
for US = 1 to 62 !US stands for 'User-System'

   !Obtain the first 7 fields from the data for the current US data, below.
   read SysNr, dKAI, uKAI, DeltaKAI, ModDeltaKAI, MaxSScore, NrReadings
   for reading = 1 to NrReadings
      read SScore, Days !Gets next data pair for current system
      plot Days, SScore !Plots point
           print #15: Str$(Days) & ", " & Str$(SScore)

      !Check for range
      if MinS > SScore then let MinS = SScore
      if MaxS < SScore then let MaxS = SScore
```

```
      !Check for domain
      if LastDay < Days then let LastDay = Days
      if FirstDay > Days then let FirstDay = Days

      !Preliminaries for determination of best regression line
      let SumX = SumX + Days
      let SumY = SumY + SScore
      let SumSqX = SumSqX + Days^2
      let SumSqY = SumSqY + SScore^2
      let SumXY = SumXY + Days*SScore
      let n = n + 1
   next reading
Next US

close #15
!Determination of best regression line
let b1 = (n*SumXY - SumX*SumY)/(n*SumSqX - SumX^2)
let b0 = SumY/n - b1*SumX/n

!Plot regression line
set color "green"
let eS = b0 + b1*847
plot lines: 0, b0-.5; 0, b0+.5
plot lines: -5, b0; 5, b0
plot lines: 847, eS; 852, eS
plot lines: 847, eS+.5; 847, eS-.5

!Display statistics
plot text, at 0, 75: "b0 = " & Str$(b0)
plot text, at 0, 72: "b1 = " & Str$(b1)
plot text, at 0, 69: "S at day 847: " & Str$(eS)
plot text, at 0, 60: "Minimum S = " & Str$(MinS) & ". First Day = " & Str$(FirstDay)
plot text, at 0, 55: "Maximum S = " & Str$(MaxS) & ". Last Day = " & Str$(LastDay)

!Determine Std error of estimate
let StdEoE = Sqr((SumSqY - b0*SumY - b1*SumXY)/(n - 2))
plot text, at 0, 66: "StdEoE = " & Str$(StdEoE)

!DATA FOR 62 USs:
!Contains KAIs and overall S-Scores for each US.

!Record Structure:
!SysNr,DevKAI,UserKAI,deltaKAI,Mod(DeltaKAI), Max S-Score, NrReadings
!Reading1, after days, Reading2, after days, etc. up to 7 readings

Data 1,92,93,-1,1,37,6,25,-18,28,100,35,157,37,254,36,385,36,546
Data 2,103,104,-1,1,28.5,6,16,87,5,200,-1,268,4.5,364,28.5,487,20,640
Data 3,120,119,1,1,38,5,30,241,34,359,35,416,37,517,38,643
Data 4,108,106,2,2,40,6,33,87,39,182,40,249,40,364,40,490,40,648
Data 5,92,94,-2,2,38,3,37,54,37,149,38,248

Data 6,100,97,3,3,38,6,34,87,26,197,24,266,31,364,32,490,38,652
Data 7,91,88,3,3,30.5,7,26,86,25,196,30.5,249,25,360,13.5,506,16,626,17,648
Data 8,91,88,3,3,40,7,32,142,38,234,39,327,40,390,36,562,40,646,38,719
Data 9,106,110,-4,4,33,3,23,36,32,141,33,205
Data 10,97,92,5,5,40,7,0,-12,31,78,36,177,38,231,40,345,40,450,40,577
```

Data 11,90,85,5,5,38,6,36,64,38,160,38,263,38,362,38,456,38,567
Data 12,90,95,-5,5,40,5,30,332,37,426,40,505,40,597,32,707
Data 13,100,94,6,6,34,3,26,11,31,127,34,191
Data 14,106,99,7,7,19,6,9,86,6,210,0,266,15,366,19,568,19,626
Data 15,118,110,8,8,40,6,36,123,36,190,35,294,39,392,39,480,40,598

Data 16,100,92,8,8,38,6,31,357,37,439,38,543,38,641,38,729,38,847
Data 17,99,90,9,9,39,6,37,123,39,221,38,325,29,421,31.5,508,29.5,626
Data 18,99,89,10,10,38,6,31,123,38,221,38,322,32,409,36,527,36,638
Data 19,101,89,12,12,40,5,30,79,37,210,38,364,40,527,40,644
Data 20,87,99,-12,12,29,6,29,87,24,210,22,266,21,364,24,487,23,640

Data 21,101,89,12,12,40,6,31,63,35,154,37.5,267,39,364,40,574,40,626
Data 22,101,89,12,12,32,5,10,111,20,233,30,456,31,579,32,687
Data 23,101,89,12,12,34,6,29,156,29,247,32,415,33,513,33,619,34,740
Data 24,98,110,-12,12,39,6,39,157,39,252,39,353,39,462,39,546,39,679
Data 25,98,110,-12,12,33,5,31,341,32,436,32,537,32,646,33,730

Data 26,100,88,12,12,40,3,31,11,37,127,40,191
Data 27,102,89,13,13,39,6,23,57,36,156,38,257,32,344,37,462,39,573
Data 28,106,92,14,14,38,7,32,86,37,182,36,249,35,360,38,483,36,568,36,648
Data 29,79,93,-14,14,40,6,40,71,40,166,40,233,38,344,40,470,40,551
Data 30,100,85,15,15,36,6,36,87,31,182,30,263,32,364,33,490,33,648

Data 31,75,90,-15,15,38,3,35,63,36,168,38,287
Data 32,101,85,16,16,18,6,18,49,14,140,14,249,14,350,9,469,9,554
Data 33,91,107,-16,16,38,7,27,139,30,231,33.5,324,36,436,38,559,35,643,36,724
Data 34,91,107,-16,16,36,6,20,155,23,247,27,346,36,402,36,513,34,600
Data 35,91,107,-16,16,39,5,18,241,30,360,25,442,38,517,39,643

Data 36,108,124,-16,16,39,6,39,356,39,432,38,575,38,698,38,783,38,841
Data 37,117,99,18,18,16,6,-1,52,12,129,9,271,16,396,2.5,478,5,538
Data 38,106,87,19,19,31.5,5,25,249,28,316,29,445,30,575,31.5,667
Data 39,113,93,20,20,40,7,32,-5,33,85,40,197,40,238,40,351,40,457,40,578
Data 40,106,86,20,20,37,3,36,72,36,187,37,251

Data 41,106,84,22,22,27,6,24,72,15,186,18,249,27,350,26,492,27,637
Data 42,71,93,-22,22,34,6,34,116,34,210,34,289,34,392,34,483,34,568
Data 43,75,97,-22,22,29,3,29,63,26,154,27,286
Data 44,117,94,23,23,15,5,-12,85,3,159,9,307,15,432,15,579
Data 45,132,109,23,23,39,3,37,225,38,341,39,405

Data 46,111,86,25,25,35,6,19,87,30,197,14,266,22,360,28,487,35,640
Data 47,102,128,-26,26,25,6,25,-55,22,40,18,141,25,239,22.5,394,23,445
Data 48,83,110,-27,27,34,5,34,-116,32,-21,33,80,33,189,33,273
Data 49,100,72,28,28,32,3,31,11,31,136,32,194
Data 50,117,88,29,29,39,5,38,113,39,188,39,294,39,487,39,598

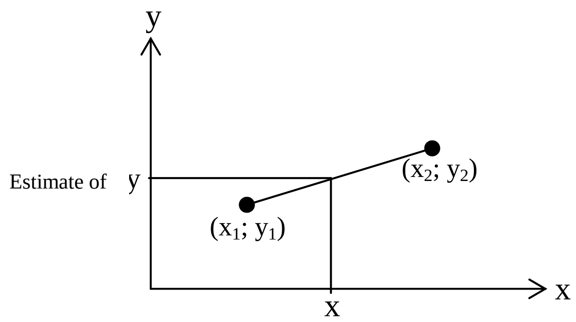
Data 51,113,82,31,31,36,6,21,-4,25,87,33,197,31,238,33,351,36,583
Data 52,125,94,31,31,25,7,14,110,24,228,19.5,354,19,451,12,546,23,658,25,671
Data 53,91,125,-34,34,36,6,31,143,31,233,31,326,33,386,35,499,36,606
Data 54,132,98,34,34,27,3,25,268,25,386,27,450
Data 55,117,81,36,36,40,5,26,85,34,158,40,294,40,447,40,567

```
Data 56,125,89,36,36,35,6,35,110,35,235,33,299,33,395,33,514,30,599
Data 57,132,96,36,36,30,3,26,15,30,120,28,184
Data 58,135,96,39,39,33,5,33,241,31,416,32,524,22,644,24,797
Data 59,135,96,39,39,36,6,33,241,31,359,31,416,36,524,34,644,35,797
Data 60,118,78,40,40,40,6,40,182,40,248,34,353,34,461,30,546,31,658

Data 61,117,75,42,42,29,6,26,57,29,134,13,238,19,336,19,424,19,542
Data 62,72,146,-74,74,8,5,6,184,0,283,-3,415,4,552,8,702

END PROGRAM
```

Appendix 5.2

Linear Interpolation: theoretical method of estimation

According to Steffens and Strydom (2004) linear interpolation is a *numerical technique* for estimating the value of a function lying between two known values. The diagram below illustrates the method. A value of y is required for some x. However, all that is known about the function are the points (x_1; y_1) and (x_2; y_2). (x_1; y_1) and (x_2; y_2) are joined by a straight line, and the *estimate* of y is obtained from the resultant straight line function.



Steffens et al. (2004) give the following formula:

$$\text{Estimate of } y = y_1 + \frac{x - x_1}{x_2 - x_1} \cdot (y_2 - y_1)$$

Translated into True BASIC® code, this becomes:

```
Let y = y1 +  (x-x1)/(x2-x)*(y2-y1)
```

Replacing x by Days, x1 by DaysL (L for low), x2 by DaysH (H for high), y by the corresponding element of the S-array, y1 by SScoreL and y2 by SScoreH, the actual line of program code to do the calculation is derived, thus:

```
let S(Sys, Days) = SScoreL+(Days-DaysL)/(DaysH-DaysL)*(SScoreH-SScoreL)
```

(see Programs 5.3.1 and 5.3.2 below)

5.2.1 Program to generate unsmoothed curve of S on time

This program uses linear interpolation (see Appendix 5.2 above) to produce all the S-Score data over usage time, for all 62 USs. Although the program is designed to produce data from 0 to 830 days, it is also designed to ignore daily data where fewer than 10 USs are in operation. The program plots the unsmoothed mean S against time in days, which is recovered from the screen by taking a screen shot. Documentation is given throughout the program code. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements. Since these are identical to those of the program given in Appendix 5.1, they are not repeated here (see End of program).

```
PROGRAM SystemUsageLifeCycle

!INTRODUCTION:

!SECTION A:
!This part of the program produces all the reliable S-Score data over a system
!development time, from days 0 to 830 iro installation date, by
!interpolation, for all 62 USs.


!SECTION B:
!This section plots the mean S-Score against time in days.


!SECTION A: PRODUCE DATA FOR DAYS 0 to 830

Dim S(62, 0 to 830) !defines matrix to hold 64 x850 S-Scores,
                    !most interpolated.

Dim MeanS(0 to 830) !will contain mean S-Score for each day

!Assign -1000 to each element of the S-array
mat S = (-1000)


!Assigning S-Scores to S( , )

for US = 1 to 62

   !Obtain the first 7 fields from the data for the current system, below.
   read SysNr, DevKAI, UserKAI, DeltaKAI, ModDeltaKAI, MaxSScore, NrReadings


   !Read the first data pair, which are the first SScore after so many Days
   read SScoreH,  DaysH

   !Read and process remaining data in pairs of pairs, perfoming linear
   !interpolation as you go.  The lower Days value is at the low interval
   !end.
```

```
   for reading = 1 to NrReadings-1 !must only go to 1 less than last reading.
      !Make low-end-of-interval data pair the last high-end pair
      let SScoreL = SScoreH
      let DaysL = DaysH
      !Get next high-end pair
      read SScoreH, DaysH !Gets next data pair for current system
      !Perform linear interpolation, and hence give approx. S-Scores
      !for all days from DaysL to DaysH.
      for Days = DaysL to DaysH
         if days <= 830 and Days >= 0 then
           let S(US, Days) = SScoreL+(Days-DaysL)/(DaysH-DaysL)*(SScoreH-SScoreL)
           !Avoid spurious accuracy by expressing to 1 decimal place only
           let S(US, Days) = Int(S(US, Days)*10)/10
         end if
      next Days
   next reading
next US

!Determine the mean S-Score for each day
For Day = 0 to 830
   let DayCount = 0
   For Sys = 1 to 62
      If S(Sys, Day) > -1000 then
        let DayCount = DayCount + 1
        let MeanS(Day) = MeanS(Day) + S(Sys, Day)
      End If
   Next Sys
   If DayCount > 0 then
     let MeanS(Day) = MeanS(Day)/DayCount
   else
     let MeanS(Day) = 0
   end if
Next Day

!SECTION B:  GRAPH RESULTS
set window 0, 830, 20, 40
set back "white"
set color "red"
for i = 0 to 830 step 30
   plot lines: i, 20; i, 20.3
next i
plot lines: 0, 20; 830, 20
for i = 20 to 40 step 5
   plot lines: 0, i; 10, i
next i
plot lines: 0, 20; 0, 40
!Plot the curve
set color "green"
for Day = 0 to 830
   plot lines: Day, MeanS(Day);
next Day
plot lines: 830, MeanS(830)

!END MAIN PROGRAM
```

Data statements follow. As they are identical to the data statements of the program shown in Appendix 5.1, they are not repeated here.

```
END PROGRAM
```

5.2.2: Program to generate smoothed curve of S on time

This program uses linear interpolation (see Appendix 5.2 above) to produce all the S-Score data over usage time, for all 62 USs. Although the program is designed to produce data from 0 to 830 days, it is also designed to ignore daily data where fewer than 10 USs are in operation. The program produces smoothed data by way of 31-day moving averages. These data are written to a file called **SValues.csv**. They are displayed in Appendix 5.3 below. The program plots the smoothed mean S-Scores against time in days, which is recovered from the screen by taking a screen shot. The program uses Student-t (not the Kendall-t) values also found in the data statements, to produce confidence bands for the population curve at the 50%, 80%, 90%, 95%, 99% and 99.5% levels. Documentation is given throughout the program code. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements. The first set of these are tables of the Student-t Distribution. The second set are identical to those of the program given in Appendix 5.1, hence they are not repeated here (see End of program).

```
PROGRAM SystemUsageLifeCycleSmoothed

!INTRODUCTION:

!SECTION A:
!This section assigns the Student-t (not the Kendall-t) values to the program !variables.
!This part of the program produces all the reliable S-Score data over a system
!development time, from days 0 to 830 iro installation date, by
!interpolation, for all 62 USs.


!SECTION B:
!This section plots the mean S-Score against time in days.


!SECTION A: PRODUCE DATA FOR DAYS 0 to 830
Dim S(62, 0 to 830) !defines matrix to hold 64 x 831 (0-830) S-Scores,
                    !most interpolated.
Dim t(6, 62) !defines matrix to hold Student-t values
Dim NrUSs(0 to 830) !will contain the number of USs for each day
Dim MeanS(0 to 830) !will contain mean S-Score for each day
Dim StdDevS(0 to 830) !will contain std dev of S-Scores for each day
Dim MovAvUL(30 to 830)
Dim MovAvS(30 to 830)
Dim MovAvLL(30 to 830)
Dim ULim(0 to 830) !will contain upper confidence limits
Dim LLim(0 to 830) ! "     "    lower    "        "

!Assign no-data signal of -1000 to each element of the S-array
mat S = (-1000)
```

```
Dim St250(62) !defines array to hold Student-t values trapping upper 25% area
Dim St100(62) !defines array to hold Student-t values trapping upper 10% area
Dim St050(62) !defines array to hold Student-t values trapping upper 5% area
Dim St025(62) !defines array to hold Student-t values trapping upper 2.5% area
Dim St010(62) !defines array to hold Student-t values trapping upper 1% area
Dim St005(62) !defines array to hold Student-t values trapping upper 0.5% area

!Assign values to Student-t variables, in order:
!t(1,62) 25%, t(2,62) 10%, t(3,62) 5%,
!t(4,62) 2.5%, t(5,62) 1% and t(6,62) .5%

For Level = 1 to 6
   For DegFre = 1 to 62
      read t(Level,DegFre)
   Next DegFre
Next Level

!Assigning S-Scores to S( , )

for US = 1 to 62

   !Obtain the first 7 fields from the data for the current US data, below.
   read SysNr, aKAI, uKAI, DeltaKAI, ModDeltaKAI, MaxSScore, NrReadings

   !Read the first data pair, which are the first SScore after so many Days
   read SScoreH,  DaysH

   !Read and process remaining data in pairs of pairs, perfoming linear
   !interpolation as you go.  The lower Days value is at the low interval
   !end.
   for reading = 1 to NrReadings-1 !must only go to 1 less than last reading.

      !Make low-end-of-interval data pair the last high-end pair
      let SScoreL = SScoreH
      let DaysL = DaysH

      !Get next high-end pair
      read SScoreH, DaysH !Gets next data pair for current system

      !Perform linear interpolation, and hence give approx. S-Scores
      !for all days from DaysL to DaysH.
      for Days = DaysL to DaysH
         if days <= 830 and Days >= 0 then
            let S(US, Days) = SScoreL+(Days-DaysL)/(DaysH-DaysL)*(SScoreH-SScoreL)

            !Avoid spurious accuracy by expressing to 1 decimal place only
            let S(US, Days) = Int(S(US, Days)*10)/10
         end if

      next Days

   next reading

next US
```

```
!Determine Number of USs and hence mean S-Score & StdDev for each day

For Day = 0 to 830
   let SumSqDevs = 0
   For US = 1 to 62
      If S(US, Day) > -1000 then
        let MeanS(Day) = MeanS(Day) + S(US, Day)
        let NrUSs(Day) = NrUSs(Day) + 1
      End If
   Next US

   If NrUSs(Day) > 1 then
     let MeanS(Day) = MeanS(Day)/NrUSs(Day)
     For US = 1 to 62
        If S(US, Day) > -1000 then let SumSqDevs = SumSqDevs + (S(US, Day)
                                                                     - MeanS(Day))^2

     next US
     let Variance = SumSqDevs/(NrUSs(Day) - 1)
     let StdDevS(Day) = Sqr(Variance)

   end if

Next Day

!SECTION B:  DETERMINE VALUES AND GRAPH RESULTS
!Draw coordinates
set window 0, 830, 20, 40
set back "white"
set color "red"
for i = 0 to 830 step 30
   plot lines: i, 20; i, 20.2
next i

for i = 0 to 830 step 90
   plot lines: i, 20; i, 20.4
next i

plot lines: 0, 20; 830, 20
for i = 20 to 40 step 5
   plot lines: 0, i; 12, i
next i

for i = 20 to 40
   plot lines: 0, i; 7, i
next i

!for i = 0 to -1 step -.1
!    plot lines: 0, i; 10, i
!next i
plot lines: 0, 20; 0, 40

!Determine moving average values for principal curve
for Day = 30 to 810
   let MovTotal = 0
   let NrReadings = 0
   for i = 0 to 30
      if MeanS(Day - i) >0 then
        let MovTotal = MovTotal + MeanS(Day - i)
```

```
        let NrReadings = NrReadings + 1
      end if
    next i

    if NrReadings > 0 then let MovAvS(Day) = MovTotal/NrReadings

next Day

let MinUSs = 20

!Plot the principal curve
set color "green"
for Day = 30 to 795
    plot lines: Day-15, MovAvS(Day);
next Day
plot lines: 780, MovAvS(795)

set color "brown"! for confidence level curves

!Plot six sets of confidence curves
For Level = 1 to 6
     !Determine upper and lower confidence limits
     for Day = 30 to 810
        let ConfidenceRadius = t(Level, NrUSs(Day) - 1) * StdDevS(Day)
                                                        / Sqr(NrUSs(Day))
        let ULim(Day) = MeanS(Day) + ConfidenceRadius
        let LLim(Day) = MeanS(Day) - ConfidenceRadius

        let MovTotalUL = 0
        let MovTotalLL = 0

        for i = 0 to 30
            let MovTotalUL = MovTotalUL + ULim(Day - i)
            let MovTotalLL = MovTotalLL + LLim(Day - i)
        next i

        let MovAvUL(Day) = MovTotalUL/31
        let MovAvLL(Day) = MovTotalLL/31

     next Day

     !Plot the upper confidence limit
     for Day = 0 to 830
        if NrUSs(Day)>MinUSs then plot lines: Day-15, MovAvUL(Day);
        if NrUSs(Day)<=MinUSs and Day>100 then
           plot lines: Day-16, MovAvUL(Day-1)
           exit for
        end if
     next Day

     !Plot the lower confidence limit
     for Day = 0 to 830
        if NrUSs(Day)>MinUSs then plot lines: Day-15, MovAvLL(Day);
        if NrUSs(Day)<=MinUSs and Day>100 then
           plot lines: Day-16, MovAvLL(Day-1)
           exit for
        end if
     next Day
Next Level
```

```
!Assign mean S-Score values to table
open #15: name "e:SValues.csv", create newold, organization text, access output
erase #15
set #15: Margin 128

For Day = 30 to 830

    print #15, Using "###.##": MovAvS(Day);
    if remainder(Day-14,10) = 0 then
      print #15
    else
      print #15: ",";
    end if

next Day
close #15

!END MAIN PROGRAM

!TABLE OF STUDENT-t VALUES
!Student-t, Upper Tail .25, 1-62 degrees of freedom
Data 1.0000, .8165, .7648, .7407, .7267, .7176, .7111, .7064
Data .7027, .6998, .6974, .6955, .6938, .6924, .6912, .6901
Data .6892, .6884, .6876, .6870, .6864, .6858, .6853, .6848
Data .6844, .6840, .6837, .6834, .6830, .6828, .6825, .6822
Data .6820, .6818, .6816, .6814, .6812, .6810, .6808, .6807
Data .6805, .6804, .6802, .6801, .6800, .6799, .6797, .6796
Data .6795, .6794, .6793, .6792, .6791, .6791, .6790, .6789
Data .6788, .6787, .6787, .6786, .6785, .6785

!Student-t, Upper Tail .10, 1-62 degrees of freedom
Data 3.0777, 1.8856, 1.6377, 1.5332, 1.4759, 1.4398, 1.4149, 1.3968
Data 1.3830, 1.3722, 1.3634, 1.3562, 1.3502, 1.3450, 1.3406, 1.3368
Data 1.3334, 1.3304, 1.3277, 1.3253, 1.3232, 1.3212, 1.3195, 1.3178
Data 1.3163, 1.3150, 1.3137, 1.3125, 1.3114, 1.3104, 1.3095, 1.3086
Data 1.3077, 1.3070, 1.3062, 1.3055, 1.3049, 1.3042, 1.3036, 1.3031
Data 1.3025, 1.3020, 1.3016, 1.3011, 1.3006, 1.3002, 1.2998, 1.2994
Data 1.2991, 1.2987, 1.2984, 1.2980, 1.2977, 1.2974, 1.2971, 1.2969
Data 1.2966, 1.2963, 1.2961, 1.2958, 1.2956, 1.2954

!Student-t, Upper Tail .05, 1-62 degrees of freedom
Data 6.31380, 2.92000, 2.35340, 2.13180, 2.01500, 1.94320, 1.89460, 1.85950
Data 1.83310, 1.81250, 1.79590, 1.78230, 1.77090, 1.76130, 1.75310, 1.74590
Data 1.73960, 1.73410, 1.72910, 1.72470, 1.72070, 1.71710, 1.71390, 1.71090
Data 1.70810, 1.70560, 1.70330, 1.70110, 1.69910, 1.69730, 1.69550, 1.69390
Data 1.69240, 1.69090, 1.68960, 1.68830, 1.68710, 1.68600, 1.68490, 1.68390
Data 1.68200, 1.68110, 1.68020, 1.68010, 1.67940, 1.67870, 1.67790, 1.67720
Data 1.67660, 1.67590, 1.67530, 1.67470, 1.67410, 1.67360, 1.67300, 1.67250
Data 1.67200, 1.67160, 1.67110, 1.67060, 1.67020, 1.66980

!Student-t, Upper Tail .025, 1-62 degrees of freedom
Data 12.70620, 4.30270, 3.18240, 2.77640, 2.57060, 2.44690, 2.36460, 2.30600
Data 2.26220, 2.22810, 2.20100, 2.17880, 2.16040, 2.14480, 2.13150, 2.11990
Data 2.10980, 2.10090, 2.09300, 2.08600, 2.07960, 2.07390, 2.06870, 2.06390
Data 2.05950, 2.05550, 2.05180, 2.04840, 2.04520, 2.04230, 2.03950, 2.03690
Data 2.03450, 2.03220, 2.03010, 2.02810, 2.02620, 2.02440, 2.02270, 2.02110
Data 2.01950, 2.01810, 2.01670, 2.01540, 2.01410, 2.01290, 2.01170, 2.01060
Data 2.00960, 2.00860, 2.00760, 2.00660, 2.00570, 2.00490, 2.00400, 2.00320
Data 2.00250, 2.00170, 2.00100, 2.00030, 1.99960, 1.99900
```

```
!Student-t, Upper Tail .01, 1-62 degrees of freedom
Data 31.82070, 6.96460, 4.54070, 3.74690, 3.36490, 3.14270, 2.99800, 2.89650
Data 2.82140, 2.76380, 2.71810, 2.68100, 2.65030, 2.62450, 2.60250, 2.58350
Data 2.56690, 2.55240, 2.53950, 2.52800, 2.51770, 2.50830, 2.49990, 2.49220
Data 2.48510, 2.47860, 2.47270, 2.46710, 2.46200, 2.45730, 2.45280, 2.44870
Data 2.44480, 2.44110, 2.43770, 2.43450, 2.43140, 2.42860, 2.42580, 2.42330
Data 2.42080, 2.41850, 2.41630, 2.41410, 2.41210, 2.41020, 2.40830, 2.40660
Data 2.40490, 2.40330, 2.40170, 2.40020, 2.39880, 2.39740, 2.39610, 2.39480
Data 2.39360, 2.39240, 2.39120, 2.39010, 2.38900, 2.38800

!Student-t, Upper Tail .005, 1-62 degrees of freedom
Data 63.65740, 9.92480, 5.84090, 4.60410, 4.03220, 3.70740, 3.49950, 3.35540
Data 3.24980, 3.16930, 3.10580, 3.05450, 3.01230, 2.97680, 2.94670, 2.92080
Data 2.89820, 2.87840, 2.86090, 2.84530, 2.83140, 2.81880, 2.80730, 2.79690
Data 2.78740, 2.77870, 2.77070, 2.76330, 2.75640, 2.75000, 2.74400, 2.73850
Data 2.73330, 2.72840, 2.72380, 2.71950, 2.71540, 2.71160, 2.70790, 2.70450
Data 2.70120, 2.69810, 2.69510, 2.69230, 2.68960, 2.68700, 2.68460, 2.68220
Data 2.68000, 2.67780, 2.67570, 2.67370, 2.67180, 2.67000, 2.66820, 2.66650
Data 2.66490, 2.66330, 2.66180, 2.66030, 2.65890, 2.65750
```

More Data statements follow. As they are identical to the data statements of the program shown in Appendix 5.1, they are not repeated here.

```
END PROGRAM
```

Appendix 5.3

Program to conduct Bartlein's (2005) test for equality of means

This program uses linear interpolation (see Appendix 5.2 above) to produce all the S-Score data over usage time, for all 62 USs. Although the program is designed to produce data from 0 to 830 days, it is also designed to ignore daily data where fewer than 10 USs are in operation. The program tests pairs of means for a significant difference, and writes the consequent statistical data to: **TestMnSPrs.csv** . Documentation is given throughout the program code. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements. Since they are identical to those of the program given in Appendix 5.1, they are not repeated here (see End of program).

```
PROGRAM PointwiseTestsForEqualityOfMeans

!SECTION A: PRODUCE DATA FOR DAYS 0 to 730

Dim S(62, 0 to 730) !defines matrix to hold 62 x 831 (0-830) S-Scores,
                    !most interpolated.
Dim NrUSs(0 to 730) !will contain the number of users for each day
Dim MeanS(0 to 730) !will contain mean S-Score for each day
Dim StdDevS(0 to 730) !will contain std dev of S-Scores for each day

!Assign no-data signal of -1000 to each element of the S-array
mat S = (-1000)

!Assigning S-Scores to S( , )

for US = 1 to 62

  !Obtain the first 7 fields from the data for the current user data, below.
  read SysNr, DevKAI, UserKAI, DeltaKAI, ModDeltaKAI, MaxSScore, NrReadings

  !Read the first data pair, which are the first SScore after so many Days
  read SScoreH,  DaysH

  !Read and process remaining data in pairs of pairs, perfoming linear
  !interpolation as you go.  The lower Days value is at the low interval
  !end.
  for reading = 1 to NrReadings-1 !must only go to 1 less than last reading.

    !Make low-end-of-interval data pair the last high-end pair
    let SScoreL = SScoreH
    let DaysL = DaysH

    !Get next high-end pair
    read SScoreH, DaysH !Gets next data pair for current system

    !Perform linear interpolation, and hence give approx. S-Scores
    !for all days from DaysL to DaysH.
```

```
        for Days = DaysL to DaysH
           if days <= 730 and Days >= 0 then
              let S(US, Days) = SScoreL+(Days-DaysL)/(DaysH-DaysL)*(SScoreH-SScoreL)

              !Avoid spurious accuracy by expressing to 1 decimal place only
              let S(US, Days) = Int(S(US, Days)*10)/10
           end if

        next Days
    next reading
next US

!Assign Student-t values, with degrees of freedom, to table
open #15: name "e:TestMnSPrs.csv", create newold, organization text, access output
erase #15
set #15: Margin 128
Print #15: "Arc" & "," & "Student-t" & "," & "Degs Freedom" & "," & "No Readings; 1st point" &
"," & "No. Readings; last point"

!Arc an
let Lable$ = "an"
let Day1 = 0
let Day2 = 717
call DifferenceBetweenMeans

!Arc bm
let Lable$ = "bn"
let Day1 = 48
let Day2 = 717
call DifferenceBetweenMeans

!Arc cn
let Lable$ = "cn"
let Day1 = 52
let Day2 = 717
call DifferenceBetweenMeans

!Arc bj
let Lable$ = "bj"
let Day1 = 48
let Day2 = 555
call DifferenceBetweenMeans

!Arc cj
let Lable$ = "cj"
let Day1 = 52
let Day2 = 555
call DifferenceBetweenMeans

!Arc ab
let Lable$ = "ab"
let Day1 = 0
let Day2 = 48
call DifferenceBetweenMeans

!Arc bc
let Lable$ = "bc"
let Day1 = 48
let Day2 = 52
```

```
call DifferenceBetweenMeans

!Arc cd
let Lable$ = "cd"
let Day1 = 52
let Day2 = 84
call DifferenceBetweenMeans

!Arc de
let Lable$ = "de"
let Day1 = 84
let Day2 = 86
call DifferenceBetweenMeans

!Arc eg
let Lable$ = "eg"
let Day1 = 86
let Day2 = 183
call DifferenceBetweenMeans

!Arc fg
let Lable$ = "fg"
let Day1 = 111
let Day2 = 183
call DifferenceBetweenMeans

!Arc cg
let Lable$ = "cg"
let Day1 = 52
let Day2 = 183
call DifferenceBetweenMeans

!Arc ag
let Lable$ = "ag"
let Day1 = 0
let Day2 = 183
call DifferenceBetweenMeans

!Arc gh
let Lable$ = "gh"
let Day1 = 183
let Day2 = 288
call DifferenceBetweenMeans

!Arc hi
let Lable$ = "hi"
let Day1 = 288
let Day2 = 538
call DifferenceBetweenMeans

!Arc hj
let Lable$ = "hj"
let Day1 = 288
let Day2 = 555
call DifferenceBetweenMeans

!Arc in
let Lable$ = "in"
let Day1 = 538
```

```
let Day2 = 717
call DifferenceBetweenMeans
close #15
Print "DONE."
get key: Key

SUB DifferenceBetweenMeans
let Day = Day1
call StatsForDay
let Day = Day2
call StatsForDay
let Realt = (MeanS(Day2)-MeanS(Day1))/Sqr(StdDevS(Day1)^2/NrUSs(Day1) +
StdDevS(Day2)^2/NrUSs(Day2))
let DFNuTerm1 = StdDevS(Day1)^2/NrUSs(Day1)
let DFNuTerm2 = StdDevS(Day2)^2/NrUSs(Day2)
let DFNumerator = DFNuTerm1 + DFNuTerm2
let DFDenTerm1 = (StdDevS(Day1)^2/NrUSs(Day1))/(NrUSs(Day1)-1)
let DFDenTerm2 = (StdDevS(Day2)^2/NrUSs(Day2))/(NrUSs(Day2)-1)
let DFDenomenator = DFDenTerm1 + DFDenTerm2
let DegFre = Int(DFNumerator/DFDenomenator)
print Lable$, Realt, DegFre, NrUSs(Day1), NrUSs(Day2)
Print #15: Lable$ & "," & Str$(Realt) & "," & Str$(DegFre) & "," & Str$(NrUSs(Day1)) & "," &
Str$(NrUSs(Day2))

END SUB

SUB StatsForDay
let MeanS(Day) = 0
let NrUSs(Day) = 0
let SumSqDevs = 0
For US = 1 to 62
   If S(US, Day) > -1000 then
     let MeanS(Day) = MeanS(Day) + S(US, Day)
     let NrUSs(Day) = NrUSs(Day) + 1
   End If
Next US

If NrUSs(Day) > 1 then
  let MeanS(Day) = MeanS(Day)/NrUSs(Day)
  For US = 1 to 62
    If S(US, Day) > -1000 then let SumSqDevs = SumSqDevs + (S(US, Day) -
MeanS(Day))^2
  next US
  let Variance = SumSqDevs/(NrUSs(Day) - 1)
  let StdDevS(Day) = Sqr(Variance)
end if

END SUB

!END MAIN PROGRAM
```

Data statements follow. As they are identical to the data statements of the program shown in Appendix 5.1, they are not repeated here.

```
END PROGRAM
```

Appendix 5.4

Program to conduct the Mann-Whitney test

This program uses linear interpolation (see Appendix 5.2 above) to produce all the S-Score data over usage time, for all 62 USs. Although the program is designed to produce data from 0 to 830 days, it is also designed to ignore daily data where fewer than 10 USs are in operation. The program tests pairs of means for a significant difference, and writes the consequent statistical data to: **MannWhitney.csv**. Documentation is given throughout the program code. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements. Since they are identical to those of the program given in Appendix 5.1, they are not repeated here (see End of program). (see End of program).

```
PROGRAM PointwiseMannWhitneyTestsForDifferenceOfMeans !FileName=MdSWilc


!SECTION A: PRODUCE DATA FOR DAYS 0 to 730

Dim S(62, 0 to 730) !defines matrix to hold 62 x 831 (0-830) S-Scores,
                 !most interpolated.
Dim CS(125) !Combined Ss, both days. Extra (125) to hold dummy extreme.
Dim RankCS(124) ! Ranks of the CS for both days
Dim SampleTag(124) ! 1 or 2 for sample-1 or sample-2 origin

!Assign no-data signal of -1000 to each element of the S-array
mat S = (-1000)


!Assigning S-Scores to S( , )

for US = 1 to 62

   !Obtain the first 7 fields from the data for the current user data, below.
   read SysNr, DevKAI, UserKAI, DeltaKAI, ModDeltaKAI, MaxSScore, NrReadings

   !Read the first data pair, which are the first SScore after so many Days
   read SScoreH,  DaysH

   !Read and process remaining data in pairs of pairs, perfoming linear
   !interpolation as you go.  The lower Days value is at the low interval
   !end.
   for reading = 1 to NrReadings-1 !must only go to 1 less than last reading.

      !Make low-end-of-interval data pair the last high-end pair
      let SScoreL = SScoreH
      let DaysL = DaysH

      !Get next high-end pair
      read SScoreH, DaysH !Gets next data pair for current system
```

```
      !Perform linear interpolation, and hence give approx. S-Scores
      !for all days from DaysL to DaysH.
      for Days = DaysL to DaysH
         if days <= 730 and Days >= 0 then
            let S(US, Days) = SScoreL+(Days-DaysL)/(DaysH-DaysL)*(SScoreH-SScoreL)

            !Avoid spurious accuracy by expressing to 1 decimal place only
            let S(US, Days) = Int(S(US, Days)*10)/10
         end if

      next Days
   next reading
next US

!SECTION B: SELECTION OF POINT PAIRS FOR TESTING

!Assign U-values, with degrees of freedom, to table as text file
open #15: name "e:MannWhitney.csv", create newold, organization text, access output
erase #15
set #15: Margin 128
!Title
Print #15: "Arc, U1, n1, U2, n2, R1 + R2, N(N + 1)/2, Z1, Z2"

!Arc an
let Lable$ = "an"
let Day1 = 0
let Day2 = 717
call DifferenceBetweenMeans

!Arc bm
let Lable$ = "bn"
let Day1 = 48
let Day2 = 717
call DifferenceBetweenMeans

!Arc cn
let Lable$ = "cn"
let Day1 = 52
let Day2 = 717
call DifferenceBetweenMeans

!Arc bj
let Lable$ = "bj"
let Day1 = 48
let Day2 = 555
call DifferenceBetweenMeans

!Arc cj
let Lable$ = "cj"
let Day1 = 52
let Day2 = 555
call DifferenceBetweenMeans

!Arc ab
let Lable$ = "ab"
let Day1 = 0
let Day2 = 48
call DifferenceBetweenMeans
```

```
!Arc bc
let Lable$ = "bc"
let Day1 = 48
let Day2 = 52
call DifferenceBetweenMeans

!Arc cd
let Lable$ = "cd"
let Day1 = 52
let Day2 = 84
call DifferenceBetweenMeans

!Arc de
let Lable$ = "de"
let Day1 = 84
let Day2 = 86
call DifferenceBetweenMeans

!Arc eg
let Lable$ = "eg"
let Day1 = 86
let Day2 = 183
call DifferenceBetweenMeans

!Arc fg
let Lable$ = "fg"
let Day1 = 111
let Day2 = 183
call DifferenceBetweenMeans

!Arc cg
let Lable$ = "cg"
let Day1 = 52
let Day2 = 183
call DifferenceBetweenMeans

!Arc ag
let Lable$ = "ag"
let Day1 = 0
let Day2 = 183
call DifferenceBetweenMeans

!Arc gh
let Lable$ = "gh"
let Day1 = 183
let Day2 = 288
call DifferenceBetweenMeans

!Arc hi
let Lable$ = "hi"
let Day1 = 288
let Day2 = 538
call DifferenceBetweenMeans

!Arc hj
let Lable$ = "hj"
let Day1 = 288
let Day2 = 555
```

```
call DifferenceBetweenMeans

!Arc hn
let Lable$ = "hn"
let Day1 = 288
let Day2 = 717
call DifferenceBetweenMeans

!Arc in
let Lable$ = "in"
let Day1 = 538
let Day2 = 717
call DifferenceBetweenMeans

close #15
Print "DONE."
get key: Key

!SECTION C: PROCEDURE: MANN-WHITNEY CALCULATION OF U-STATISTIC

SUB DifferenceBetweenMeans
!Count USs for Day1 and Day2
let USs1 = 0
let USs2 = 0
for i = 1 to 62
   if S(i, Day1) > -1000 then let USs1 = USs1 + 1
   if S(i, Day2) > -1000 then let USs2 = USs2 + 1
next i

!Assign two sets of S-values to the common array CS and tag origins
mat CS = 0
mat SampleTag = 0
for i = 1 to 62
  let CS(i) = S(i, Day1)
  let SampleTag(i) = 1
  let CS(i + 62) = S(i, Day2)
  let SampleTag(i + 62) = 2
next i

!Sort CS array in ascending order, carrying sample tags with values
for i = 1 to 124
   let SwapTest = 0
   for j = 1 to 123
      if CS(j+1) < CS(j) then
         let Temp = CS(j)       !to swap values
         let CS(j) = CS(j + 1)
         let CS(j + 1) = Temp

         let Temp = SampleTag(j) !to swap sample tags
         let SampleTag(j)= SampleTag(j + 1)
         let SampleTag(j + 1) = Temp

         let SwapTest = 1
      end if
   next j
   if SwapTest = 0 then exit for
next i

!Assign ranks to RankCS array
```

```
mat RankCS = 0
let Rank = 0
for i = 1 to 124
   if CS(i) > -1000 then
     let Rank = Rank + 1
     let RankCS(i) = Rank
   end if
next i

!Average ranks where ties occur
let i = 1
let CS(125) = 1000 !making it > CS(124) to terminate loop
do
  let LocalTotal = RankCS(i)
  let LocalNr = 1
  for j = i + 1 to 125 !must reach dummy extreme CS(125)
     if CS(j) = CS(j - 1) then
       let LocalTotal = LocalTotal + RankCS(j)
       let LocalNr = LocalNr + 1
     else
       let LocalMeanRank = LocalTotal/LocalNr
       for k = i to j - 1
          let RankCS(k) = LocalMeanRank
       next k
       let i = j
       exit for
     end if
  next j
  if j > 124 then exit do
loop

!Determine sample sums R1 and R2
let R1 = 0
let R2 = 0
for i = 1 to 124
   if SampleTag(i) = 1 then let R1 = R1 + RankCS(i)
   if SampleTag(i) = 2 then let R2 = R2 + RankCS(i)
next i

!Determine test statistics U1 and U2
let U1 = USs1*USs2 + USs1*(USs1 + 1)/2 - R1
let U2 = USs1*USs2 + USs2*(USs2 + 1)/2 - R2

!Determine large sample test statistics Z1 and Z2
let N = USs1 + USs2
let UMean = USs1*USs2/2
let UStdDev = Sqr(USs1*USs2*(N - 1)/12)
let Z1 = (U1 - UMean)/UStdDev
let Z2 = (U2 - UMean)/UStdDev

Print #15: Lable$ & "," & Str$(U1) & "," & Str$(USs1) & "," & Str$(U2) & "," & Str$(USs2) & ","
& Str$(R1 + R2) & "," & Str$(N*(N + 1)/2) & "," & Str$(Z1) & "," & Str$(Z2)

END SUB
```

Data statements follow. As they are identical to the data statements of the program shown in Appendix 5.1, they are not repeated here.

```
END PROGRAM
```

Appendix 5.5

Program to graph cognitive model relevancies (as Kendall-t_a)

(Written in True BASIC © by the author)

This program outputs the graph of **t_a** against **system usage time**, measured in days since usage started. It thus incorporates and calls the **kernel to calculate Kendall-t** values called **KendallKernel**. This was pilot-tested against the SPSS® statistics package. For details, see Appendix 4.4. The graph is recovered from the screen by the taking of a screen shot. The particular cognitive model used is specified at the start of section A.1 below. Documentation is given throughout the program code. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements. Since they are identical to those of the program given in Appendix 5.1, they are not repeated here (see End of program).

```
PROGRAM Kendal_t_VersusSOnTimeUnsmoothed

!INTRODUCTION:

!SECTION A:
!This part of the program produces all the reliable S-Score data over a system
!development time, from days 0 to 830 iro installation date, by
!interpolation, for all 62 systems.

!SECTION B:
!This section then works out the associations day-wise for all reliable
!points, (62 or fewer per day), between a selected KAI measure and the
!S-Scores, as Kendall t-scores (ta).

!SECTION C:
!Finally, This section plots the Kendal t against time in days.

!SECTION A: PRODUCE DATA FOR DAYS 0 to 732
Dim KAI(62) !defines KAI value for each of 62 users, as per the
        !choice below.
Dim S(62, 0 to 830) !defines matrix to hold 64 x850 S-Scores,
              !most interpolated.
Dim Ta(0 to 850) !will contain the Kendall ta values for each day
Dim Tb(0 to 850) !will contain the Kendall tb values for each day
Dim p10(0 to 850)!will contain t-values giving sig. level of p=10%;
Dim p5(0 to 850)!similarly for p = 5%;
Dim p1(0 to 850)!similarly for p = 1%.
Dim NrSys(0 to 850) !will contain the number of user data for each day

!Assign no-data signal of -1000 to each element of the array
mat S = (-1000)

!Process all 62 users' data, assigning values to KAI() and S-Scores to S( , )

for User = 1 to 62
```

```
   !Obtain the first 7 fields from the data for the current user, below.
   read SysNr, aKAI, uKAI, DeltaKAI, ModDeltaKAI, MaxSScore, NrReadings


!SECTION A.1: Pair of statements defining desired cognitive model must have initial
    !exclamation marks (!) removed.  This converts them to active statements as opposed to
    !comments.

!CASE 1
   let KAI(User) = ModDeltaKAI
   let Label$ = "Abs KAI diff/S-Score Assoc vs Time"

!CASE 2
   !let KAI(User) = DeltaKAI !Analyst more innovative than user
   !let Label$ = "DevKAI-UserKAI/S-Score Assoc vs Time"

!CASE 3
   !let KAI(User) = uKAI
   !let Label$ = "UserKAI/S-Score Assoc vs Time"

!CASE 4
   !let KAI(User) = aKAI
   !let Label$ = "DevKAI/S-Score Assoc vs Time"

   !Read the first data pair, which are the first SScore after so many Days
   read SScoreH,  DaysH

   !Read and process remaining data in pairs of pairs, performing linear
   !interpolation as you go.  The lower Days value is at the low interval
   !end.
   for reading = 1 to NrReadings-1 !must only go to 1 less than last reading.

      !Make low-end-of-interval data pair the last high-end pair
      let SScoreL = SScoreH
      let DaysL = DaysH

      !Get next high-end pair
      read SScoreH, DaysH !Gets next data pair for current user

      !Perform linear interpolation, and hence give approx. S-Scores
      !for all days from DaysL to DaysH.
      for Days = DaysL to DaysH
         if days <= 830 and Days >= 0 then
            let S(User,Days) = SScoreL+(Days-DaysL)/(DaysH-DaysL)*(SScoreH-SScoreL)
                                  (see Appendix 5.3 for this formula)

            !Avoid spurious accuracy by expressing to 1 decimal place only
            let S(User, Days) = Int(S(User, Days)*10)/10
         end if

      next Days

   next reading
next User

Call KendallKernel
```

```
!SECTION B: DETERMINE THE KENDALL ta AND tb FOR EACH DAY

SUB KendallKernel  !Slightly modified to expedite the multiple
                                   !calculations of Kendall-t

!Declare extra variables for calculation of Kendall ta and tb
dim X(62), XRank(62), Y(62), YRank(62)
dim InVar(62), TempVar(62), TempRank(62), Rank(62)

!State the number of users' data to be analysed
let Max = 62 != maximum number of bivariate pairs (not -1000s)

!Transfer each column of S-Scores to X and Y arrays for
!determination of associations as ta and tb

For Day = 0 to 830
   let n = 0 !n will contain the number of live data in the current column
   for i = 1 to Max
      if S(i, Day) > -1000 then
        let n = n + 1
        let X(n) = S(i, Day)
        let Y(n) = KAI(i)
      end if
   next i

   if n > 9 then !Kendall t is worth calculating, so proceed to do so.
       !Main procedure to determine Kendall t
       call RankValsForKendall(X, XRank) !to determine ranks of X-array
       let U = TieFactorSum / 2
       let A1 = FirstABFactor
       let A2 = SecondABFactor

       call RankValsForKendall(Y, YRank) !to detrmine ranks of Y-array
       let V = TieFactorSum / 2
       let B1 = FirstABFactor
       let B2 = SecondABFactor

       call DetNumerator !theoretical requirement for Kendall t
       call KendallCalc !final calculation of ta and tb for current column

   else !Kendall t is not worth calculating, so assign not-valids to ta, tb
       let ta(Day) = -2
       let tb(Day) = -2
   end if
next Day

!Test display
!for i = 57 to 702
!   print i, ta(i), NrSys(i)
!   get key: key
!next i

SUB RankValsForKendall(InVar(), Rank())
mat TempVar = InVar

for j = n to 2 step -1
   for i = 2 to j
      if TempVar(i) > TempVar(i - 1) then
        let Temp = TempVar(i)
```

```
        let TempVar(i) = TempVar(i - 1)
        let TempVar(i - 1) = Temp
      end if
   next i
next j

let TieFactorSum = 0
let FirstABFactor, SecondABFactor = 0
mat Rank = 0

for j = 1 to n
   let Position = j
   let TieCount = 0
   for i = 1 to n
      if InVar(i) = TempVar(j) and Rank(i) = 0 then
        let TieCount = TieCount + 1
      end if
   next i
   for i = 1 to n
      if InVar(i) = TempVar(j) and Rank(i) = 0 then
         let Rank(i) = Position + TieCount/2 -1/2
      end if
   next i
   let TieFactorSum = TieFactorSum + TieCount*(TieCount - 1)
   let FirstABFactor = FirstABFactor + TieCount*(TieCount - 1)*(TieCount - 2)
   let SecondABFactor = SecondABFactor + TieCount*(TieCount - 1)*(2*TieCount + 5)

   let j = j + TieCount - 1
next j

END SUB

SUB DetNumerator
let Sum = 0

for j = 1 to n - 1
   for i = j + 1 to n

      if XRank(i) > XRank(j) then
        let XMultiplier = 1
      else if XRank(i) < XRank(j) then
        let XMultiplier = -1
      else
        let XMultiplier = 0
      end if

      if YRank(i) > YRank(j) then
        let YMultiplier = 1
      else if YRank(i) < YRank(j) then
        let YMultiplier = -1
      else
        let YMultiplier = 0
      end if

      let Sum = Sum + XMultiplier * YMultiplier
   next i
next j

END SUB
```

```
SUB KendallCalc
let SVar = ((n*n-n)*(2*n+5)-A2-B2)/18  +  A1*B1/((9*n*n-9*n)*(n-2))  +  2*U*V / (n*n-n)
let Ta(Day) = 2*Sum/(n*n - n)
let TaVar = 4*SVar / (n*n - n)^2
let TaSD = Sqr(TaVar)
let Taz = Ta(Day) / TaSD

let Tb(Day) = Sum / Sqr(n*n/2 - n/2 - U) / Sqr(n*n/2 - n/2 - V)
let TbVar = SVar / (n*n/2 - n/2 - U) / (n*n/2 - n/2 - V)
let TbSD = Sqr(TbVar)
let Tbz = Tb(Day) / TbSD

let NrSys(Day) = n
let p10(Day) = -Int(1.19*Abs(TaSD)*100 +.5)/100
let p5(Day) = -Int(1.64*Abs(TaSD)*100 +.5)/100
let p1(Day) = -Int(2.32*Abs(TaSD)*100 +.5)/100

END SUB

!SECTION C:  GRAPH RESULTS
set window 0, 830, -1, 1
set back "white"
set color "red"
for i = 0 to 810 step 30
   plot lines: i, 0; i, .02
next i
plot lines: 0, 0; 810, 0
for i = 0 to 1 step .1
   plot lines: 0, i; 10, i
next i
for i = 0 to -1 step -.1
   plot lines: 0, i; 10, i
next i
plot lines: 0, 1; 0, -1

plot text, at 20, .3: Label$ !from initial choice

!Plot significance level curves for p=10%, 5% and 1%
for Day = 0 to 830
   plot lines: Day, p10(Day);
next Day
plot lines: 830, p10(830)

for Day = 0 to 830
   plot lines: Day, p5(Day);
next Day
plot lines: 830, p5(830)

for Day = 0 to 830
   plot lines: Day, p1(Day);
next Day
plot lines: 830, p1(830)

!Plot the curve
set color "green"
for Day = 0 to 830
   if ta(Day)>-2 then plot lines: Day, Ta(Day);
```

```
next Day
if Ta(830)>-2 then plot lines: 830, Ta(830)

!Assign ta values to table together with their significances
open #15: name "e:taValues.dat", create newold, organization text, access output
erase #15
set #15: Margin 128
For Day = 0 to 830

     print #15, Using "#.####": ta(Day);

     if ta(Day) <= p1(Day) and ta(Day)>-2 then
       print #15: "@.01";
     else if ta(Day) <= p5(Day) and ta(Day)>-2 then
       print #15: "@.05";
     else if ta(Day) <= p10(Day) and ta(Day)>-2 then
       print #15: "@.10";
     else
       print #15: "****";
     end if

     if remainder(Day+1,10) = 0 then
       print #15
     else
       print #15: ",";
     end if

next Day

close #15

!END MAIN PROGRAM
```

Data statements follow. As they are identical to the data statements of the program shown in Appendix 5.1, they are not repeated here.

```
END PROGRAM
```

Appendix 5.6

Processing of individual problem severities

(Written in True BASIC © by the author)

5.6.1 Program to graph mean problem severities on time (204 problems over 40 systems)

The program plots S against time in days, for all the S-Score readings actually taken. The output is recovered from the screen by taking a screen shot. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements (see End of program).

```
PROGRAM PlotMeanProblemSeverity

!DEFINE ARRAYS
dim CurrProblemOnDay(-20 to 1000), TotalOnDay(-20 to 1000), NumberOnDay(-20 to 1000)
clear

!PERFORM LINEAR INTERPOLTAION ON ALL PROBLEMS
for i = 1 to 204 !Maximum number of problems

   mat CurrProblemOnDay = (-1) !Assign null signal of -1 to each element

   read AnalystKAI, UserKAI, NrReadings

   !PERFORM LINEAR INTERPOLATION FOR CURRENT PROBLEM

   for j = 1 to NrReadings
      read ProblemSeverity, Day


      let CurrProblemOnDay(Day) = ProblemSeverity

      if j>1 then
        for k = StartDay + 1 to Day - 1
           let CurrProblemOnDay(k) = CurrProblemOnDay(StartDay) +
                  (k - StartDay)*(CurrProblemOnDay(Day) –
                  CurrProblemOnDay(StartDay))/(Day - StartDay)
        next k
      end if

      let Rs = ProblemSeverity
      let StartDay = Day

   next j

   for j = -20 to 1000
      if CurrProblemOnDay(j) > -1 then
        let TotalOnDay(j) = TotalOnDay(j) + CurrProblemOnDay(j)
        let NumberOnDay(j) = NumberOnDay(j) + 1
      end if
   next j

next i
```

```
!SET UP DISPLAY WINDOW
clear
set window -100, 800, -.2, 4.8
set back "white"
set color "red"

!DRAW AXES
plot lines: 0, -1; 0, 5
for i = 2 to 5
   plot lines: -5, i; 5, i
next i
plot lines: -10, 1; 5, 1

plot lines: -20, 0; 800, 0
for i = 0 to 1000 step 30
   if i/180 = int(i/180) then
      plot lines: i, -.1;  i, .1
   else
      plot lines: i, -.05;  i, .05
   end if
next i

!PLOT MEAN PROBLEM CURVE
for i = -20 to 1000
   if NumberOnDay(i) > 0 then plot i, TotalOnDay(i)/NumberOnDay(i);
next i
plot

!END MAIN PROGRAM CODING

!DATA
!Record Structure: AnalystKAI, UserKAI, NrReadings, Reading1, Days1, etc.

!User System 1
data 113, 93, 7, 7, -5, 7, 85, 0, 197, 0, 238, 0, 351, 0, 457, 0, 578
data 113, 93, 7, 2, -5, 1, 85, 1, 197, 1, 238, 1, 351, 1, 457, 1, 578

!User System 2
data 113, 82, 6, 7, -4, 5, 87, 2, 197, 3, 238, 3, 351, 0, 583
data 113, 82, 6, 5, -4, 5, 87, 3, 197, 3, 238, 2, 351, 3, 583
data 113, 82, 6, 6, -4, 5, 87, 2, 197, 3, 238, 2, 351, 1, 583
data 113, 82, 6, 2, -4, 1, 87, 1, 197, 1, 238, 1, 351, 1, 583

!User System 3
data 97, 92, 7, 7, -12, 3, 78, 0, 177, 0, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 6, -12, 0, 78, 0, 177, 0, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 4, -12, 0, 78, 0, 177, 0, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 7, -12, 0, 78, 0, 177, 0, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 2, -12, 2, 78, 0, 177, 0, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 4, -12, 4, 78, 4, 177, 2, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 7, -12, 0, 78, 0, 177, 0, 231, 0, 345, 0, 450, 0, 577
data 97, 92, 7, 4, -12, 1, 78, 1, 177, 1, 231, 1, 345, 1, 450, 1, 577

!User System 4
data 92, 93, 6, 6, -18, 0, 100, 0, 157, 0, 254, 0, 385, 0, 546
data 92, 93, 6, 2, -18, 4, 100, 1, 157, 0, 254, 0, 385, 0, 546
data 92, 93, 6, 6, -18, 6, 100, 3, 157, 0, 254, 0, 385, 0, 546
data 92, 93, 6, 0, -18, 0, 100, 0, 157, 2, 254, 0, 385, 3, 546
data 92, 93, 6, 0, -18, 0, 100, 0, 157, 0, 254, 3, 385, 0, 546
```

```
data 92, 93, 6, 2, -18, 3, 100, 2, 157, 2, 254, 2, 385, 2, 546

!User System 5
data 101, 89, 5, 6, 79, 1, 210, 1, 364, 0, 527, 0, 644
data 101, 89, 5, 2, 79, 1, 210, 1, 364, 0, 527, 0, 644
data 101, 89, 5, 3, 79, 2, 210, 1, 364, 1, 527, 1, 644

!User System 6
data 111, 86, 6, 5, 87, 2, 197, 5, 266, 5, 360, 2, 487, 0, 640
data 111, 86, 6, 5, 87, 4, 197, 7, 266, 2, 360, 2, 487, 2, 640
data 111, 86, 6, 7, 87, 2, 197, 4, 266, 3, 360, 2, 487, 2, 640
data 111, 86, 6, 0, 87, 0, 197, 6, 266, 4, 360, 2, 487, 0, 640
data 111, 86, 6, 5, 87, 3, 197, 5, 266, 5, 360, 5, 487, 2, 640

!User System 7
data 103, 104, 6, 5, 87, 7, 200, 7, 268, 2, 364, 0, 487, 0, 640
data 103, 104, 6, 6, 87, 6, 200, 7, 268, 7, 364, 7, 487, 7, 640
data 103, 104, 6, 7, 87, 7, 200, 7, 268, 7, 364, 3, 487, 7, 640
data 103, 104, 6, 3, 87, 5, 200, 7, 268, 7, 364, 0, 487, 0, 640
data 103, 104, 6, 0, 87, 5, 200, 7, 268, 7, 364, 0, 487, 0, 640
data 103, 104, 6, 4, 87, 6, 200, 7, 268, 6.5, 364, 2.5, 487, 7, 640

!User System 8
data 87, 99, 6, 5, 87, 5, 210, 6, 266, 5, 364, 4, 487, 4, 640
data 87, 99, 6, 3, 87, 3, 210, 3, 266, 4, 364, 4, 487, 4, 640
data 87, 99, 6, 0, 87, 5, 210, 6, 266, 7, 364, 5, 487, 6, 640
data 87, 99, 6, 4, 87, 4, 210, 4, 266, 4, 364, 4, 487, 4, 640

!User System 9
data 106, 99, 6, 6, 86, 6, 210, 6, 266, 4, 366, 4, 568, 4, 626
data 106, 99, 6, 7, 86, 7, 210, 7, 266, 0, 366, 0, 568, 0, 626
data 106, 99, 6, 7, 86, 7, 210, 7, 266, 4, 366, 4, 568, 4, 626
data 106, 99, 6, 3, 86, 3, 210, 3, 266, 0, 366, 0, 568, 0, 626
data 106, 99, 6, 3, 86, 0, 210, 0, 266, 0, 366, 0, 568, 0, 626
data 106, 99, 6, 0, 86, 5, 210, 5, 266, 5, 366, 2, 568, 2, 626
data 106, 99, 6, 0, 86, 5, 210, 5, 266, 5, 366, 5, 568, 5, 626
data 106, 99, 6, 0, 86, 0, 210, 5, 266, 5, 366, 5, 568, 5, 626
data 106, 99, 6, 6, 86, 2, 210, 3, 266, 3, 366, 2, 568, 2, 626

!User System 10
data 101, 89, 6, 4, 63, 2, 154, 0, 267, 0, 364, 0, 574, 0, 626
data 101, 89, 6, 5, 63, 2, 154, 0, 267, 0, 364, 0, 574, 0, 626
data 101, 89, 6, 0, 63, 0, 154, 2, 267, 1, 364, 0, 574, 0, 626
data 101, 89, 6, 1, 63, 2, 154, 1.5, 267, 1, 364, 1, 574, 1, 626

!User System 11
data 100, 85, 6, 3, 87, 2, 182, 2, 263, 1, 364, 0, 490, 0, 648
data 100, 85, 6, 0, 87, 5, 182, 6, 263, 5, 364, 5, 490, 5, 648
data 100, 85, 6, 2, 87, 3, 182, 3, 263, 3, 364, 3, 490, 3, 648

!User System 12
data 108, 106, 6, 6, 87, 1, 182, 0, 249, 0, 364, 0, 490, 0, 648
data 108, 106, 6, 2, 87, 1, 182, 1, 249, 1, 364, 1, 490, 1, 648

!User System 13
data 100, 97, 6, 5, 87, 5, 197, 5, 266, 5, 364, 4, 490, 0, 652
data 100, 97, 6, 0, 87, 5, 197, 5, 266, 1, 364, 1, 490, 1, 652
data 100, 97, 6, 2, 87, 5, 197, 7, 266, 4, 364, 4, 490, 2, 652
```

```
!User System 14
data 91, 88, 7, 3, 86, 0, 196, 0, 249, 0, 360, 0, 506, 0, 626, 0, 648
data 91, 88, 7, 4, 86, 5, 196, 1.5, 249, 1, 360, 4, 506, 6, 626, 6, 648
data 91, 88, 7, 5, 86, 5, 196, 1, 249, 0, 360, 0, 506, 0, 626, 0, 648
data 91, 88, 7, 0, 86, 0, 196, 6, 249, 7, 360, 3.5, 506, 6, 626, 6, 648
data 91, 88, 7, 0, 86, 0, 196, 0, 249, 7, 360, 7, 506, 7, 626, 7, 648
data 91, 88, 7, 0, 86, 0, 196, 0, 249, 0, 360, 6, 506, 1, 626, 1, 648
data 91, 88, 7, 0, 86, 0, 196, 0, 249, 0, 360, 4, 506, 2, 626, 1, 648
data 91, 88, 7, 3, 86, 6, 196, 2, 249, 1, 360, 3, 506, 3, 626, 3, 648

!User System 15
data 106, 92, 7, 5, 86, 2, 182, 2, 249, 1, 360, 1, 483, 1, 568, 1, 648
data 106, 92, 7, 1, 86, 0, 182, 0, 249, 0, 360, 0, 483, 0, 568, 0, 648
data 106, 92, 7, 1, 86, 0, 182, 0, 249, 0, 360, 0, 483, 0, 568, 0, 648
data 106, 92, 7, 0, 86, 0, 182, 1, 249, 3, 360, 0, 483, 0, 568, 0, 648
data 106, 92, 7, 0, 86, 0, 182, 0, 249, 0, 360, 0, 483, 2, 568, 2, 648
data 106, 92, 7, 2, 86, 2, 182, 2, 249, 2, 360, 2, 483, 2, 568, 2, 648

!User System 16
data 101, 85, 6, 4, 49, 4, 140, 4, 249, 4, 350, 4, 469, 4, 554
data 101, 85, 6, 5, 49, 5, 140, 5, 249, 5, 350, 5, 469, 5, 554
data 101, 85, 6, 3, 49, 3, 140, 3, 249, 3, 350, 3, 469, 3, 554
data 101, 85, 6, 3, 49, 3, 140, 3, 249, 3, 350, 3, 469, 3, 554
data 101, 85, 6, 5, 49, 5, 140, 5, 249, 5, 350, 5, 469, 5, 554
data 101, 85, 6, 0, 49, 4, 140, 4, 249, 4, 350, 4, 469, 4, 554
data 101, 85, 6, 0, 49, 0, 140, 0, 249, 0, 350, 5, 469, 5, 554
data 101, 85, 6, 3, 49, 3, 140, 3, 249, 3, 350, 3, 469, 3, 554

!User System 17
data 106, 84, 6, 6, 72, 6, 186, 6, 249, 0, 350, 2, 492, 2, 637
data 106, 84, 6, 4, 72, 4, 186, 4, 249, 4, 350, 4, 492, 3, 637
data 106, 84, 6, 5, 72, 5, 186, 0, 249, 0, 350, 0, 492, 0, 637
data 106, 84, 6, 0, 72, 5, 186, 7, 249, 7, 350, 7, 492, 7, 637
data 106, 84, 6, 2, 72, 6, 186, 6, 249, 3, 350, 2, 492, 2, 637

!User System 18
data 79, 93, 6, 0, 71, 0, 166, 0, 233, 2, 344, 0, 470, 0, 551
data 79, 93, 6, 1, 71, 1, 166, 1, 233, 1, 344, 1, 470, 1, 551

!User System 19
data 117, 81, 5, 3, 85, 0, 158, 0, 294, 0, 447, 0, 567
data 117, 81, 5, 5, 85, 0, 158, 0, 294, 0, 447, 0, 567
data 117, 81, 5, 5, 85, 5, 158, 0, 294, 0, 447, 0, 567
data 117, 81, 5, 2, 85, 2, 158, 1, 294, 1, 447, 1, 567

!User System 20
data 117, 94, 5, 6, 85, 3, 159, 3, 307, 2, 432, 2, 579
data 117, 94, 5, 6, 85, 6, 159, 1, 307, 0, 432, 0, 579
data 117, 94, 5, 3, 85, 3, 159, 1, 307, 0, 432, 0, 579
data 117, 94, 5, 6, 85, 0, 159, 1, 307, 1, 432, 1, 579
data 117, 94, 5, 7, 85, 5, 159, 5, 307, 5, 432, 6, 579
data 117, 94, 5, 3, 85, 3, 159, 3, 307, 3, 432, 2, 579
data 117, 94, 5, 4, 85, 0, 159, 0, 307, 0, 432, 0, 579
data 117, 94, 5, 5, 85, 5, 159, 5, 307, 3, 432, 3, 579
data 117, 94, 5, 6, 85, 6, 159, 6, 307, 6, 432, 6, 579
data 117, 94, 5, 4, 85, 4, 159, 1, 307, 1, 432, 1, 579
data 117, 94, 5, 0, 85, 0, 159, 3, 307, 3, 432, 3, 579
data 117, 94, 5, 3, 85, 3, 159, 3, 307, 2, 432, 2, 579
```

```
!User System 21
data 90, 85, 6, 2, 64, 0, 160, 0, 263, 0, 362, 0, 456, 0, 567
data 90, 85, 6, 2, 64, 2, 160, 2, 263, 2, 362, 2, 456, 2, 567
data 90, 85, 6, 1, 64, 1, 160, 1, 263, 1, 362, 1, 456, 1, 567

!User System 22
data 102, 89, 6, 7, 57, 2, 156, 1, 257, 2, 344, 2, 462, 1, 573
data 102, 89, 6, 7, 57, 1, 156, 0, 257, 0, 344, 0, 462, 0, 573
data 102, 89, 6, 0, 57, 0, 156, 0, 257, 5, 344, 0, 462, 0, 573
data 102, 89, 6, 4, 57, 2, 156, 2, 257, 2, 344, 2, 462, 1, 573

!User System 23
data 117, 75, 6, 3, 57, 3, 134, 4, 238, 4, 336, 4, 424, 4, 542
data 117, 75, 6, 5, 57, 3, 134, 3, 238, 3, 336, 3, 424, 4, 542
data 117, 75, 6, 3, 57, 2, 134, 2, 238, 2, 336, 2, 424, 2, 542
data 117, 75, 6, 0, 57, 2, 134, 4, 238, 4, 336, 4, 424, 2, 542
data 117, 75, 6, 0, 57, 0, 134, 5, 238, 3, 336, 3, 424, 3, 542
data 117, 75, 6, 0, 57, 0, 134, 5, 238, 1, 336, 1, 424, 3, 542
data 117, 75, 6, 4, 57, 2, 134, 5, 238, 5, 336, 5, 424, 4, 542

!User System 24
data 117, 99, 6, 2, 52, 2, 129, 2, 271, 2, 396, 3, 478, 3, 538
data 117, 99, 6, 5, 52, 0, 129, 0, 271, 0, 396, 0, 478, 0, 538
data 117, 99, 6, 5, 52, 3, 129, 5, 271, 5, 396, 6.5, 478, 7, 538
data 117, 99, 6, 5, 52, 0, 129, 0, 271, 0, 396, 0, 478, 0, 538
data 117, 99, 6, 5, 52, 5, 129, 0, 271, 0, 396, 0, 478, 0, 538
data 117, 99, 6, 2, 52, 2, 129, 2, 271, 3, 396, 4, 478, 4, 538
data 117, 99, 6, 3, 52, 2, 129, 2, 271, 2, 396, 4, 478, 4, 538
data 117, 99, 6, 5, 52, 5, 129, 5, 271, 0, 396, 0, 478, 0, 538
data 117, 99, 6, 2, 52, 3, 129, 3, 271, 0, 396, 0, 478, 0, 538
data 117, 99, 6, 5, 52, 5, 129, 6, 271, 6, 396, 6, 478, 5, 538
data 117, 99, 6, 0, 52, 0, 129, 5, 271, 5, 396, 5, 478, 5, 538
data 117, 99, 6, 0, 52, 0, 129, 0, 271, 0, 396, 4, 478, 5, 538
data 117, 99, 6, 0, 52, 0, 129, 0, 271, 0, 396, 4, 478, 0, 538
data 117, 99, 6, 3, 52, 2, 129, 2, 271, 2, 396, 2, 478, 3, 538

!User System 25
data 91, 88, 7, 7, 142, 0, 234, 0, 327, 0, 390, 0, 562, 0, 646, 0, 719
data 91, 88, 7, 0, 142, 0, 234, 0, 327, 0, 390, 3, 562, 0, 646, 0, 719
data 91, 88, 7, 0, 142, 0, 234, 0, 327, 0, 390, 0, 562, 0, 646, 2, 719
data 91, 88, 7, 2, 142, 3, 234, 2, 327, 1, 390, 2, 562, 1, 646, 1, 719

!User System 26
data 101, 89, 5, 5, 111, 2, 233, 0, 456, 0, 579, 0, 687
data 101, 89, 5, 5, 111, 4, 233, 3, 456, 2, 579, 2, 687
data 101, 89, 5, 4, 111, 4, 233, 4, 456, 4, 579, 4, 687
data 101, 89, 5, 2, 111, 2, 233, 2, 456, 2, 579, 2, 687
data 101, 89, 5, 6, 111, 6, 233, 1, 456, 1, 579, 0, 687
data 101, 89, 5, 4, 111, 1, 233, 0, 456, 0, 579, 0, 687
data 101, 89, 5, 5, 111, 2, 233, 1, 456, 1, 579, 1, 687

!User System 27
data 125, 89, 6, 2, 110, 2, 235, 2, 299, 2, 395, 2, 514, 2, 599
data 125, 89, 6, 2, 110, 2, 235, 2, 299, 2, 395, 2, 514, 2, 599
data 125, 89, 6, 0, 110, 0, 235, 2, 299, 2, 395, 2, 514, 4, 599
data 125, 89, 6, 0, 110, 0, 235, 0, 299, 0, 395, 0, 514, 1, 599
data 125, 89, 6, 2, 110, 2, 235, 2, 299, 2, 395, 2, 514, 2, 599
```

```
!User System 28
data 125, 94, 7, 3, 110, 3, 228, 3, 354, 2, 451, 2, 546, 1, 658, 1, 671
data 125, 94, 7, 5, 110, 2, 228, 3, 354, 4, 451, 5, 546, 2, 658, 1, 671
data 125, 94, 7, 5, 110, 5, 228, 5, 354, 5, 451, 5, 546, 2, 658, 2, 671
data 125, 94, 7, 6, 110, 1, 228, 1, 354, 1, 451, 2, 546, 2, 658, 2, 671
data 125, 94, 7, 2, 110, 2, 228, 1, 354, 0, 451, 1, 546, 1, 658, 1, 671
data 125, 94, 7, 4, 110, 2, 228, 3.5, 354, 4, 451, 5, 546, 3, 658, 2, 671
data 125, 94, 7, 0, 110, 0, 228, 2, 354, 3, 451, 3, 546, 3, 658, 4, 671
data 125, 94, 7, 0, 110, 0, 228, 0, 354, 0, 451, 3, 546, 2, 658, 1, 671
data 125, 94, 7, 2, 110, 2, 228, 3, 354, 3, 451, 3, 546, 2, 658, 2, 671

!User System 29
data 71, 93, 6, 3, 116, 3, 210, 3, 289, 4, 392, 4, 483, 4, 568
data 71, 93, 6, 2, 116, 2, 210, 2, 289, 1, 392, 1, 483, 1, 568
data 71, 93, 6, 2, 116, 2, 210, 2, 289, 2, 392, 2, 483, 2, 568

!User System 30
data 117, 88, 5, 1, 113, 0, 188, 0, 294, 0, 487, 0, 598
data 117, 88, 5, 2, 113, 2, 188, 2, 294, 2, 487, 2, 598

!User System 31
data 91, 125, 6, 2, 143, 2, 233, 2, 326, 1, 386, 0, 499, 0, 606
data 91, 125, 6, 1, 143, 1, 233, 1, 326, 1, 386, 1, 499, 1, 606
data 91, 125, 6, 2, 143, 2, 233, 3, 326, 2, 386, 1, 499, 0, 606
data 91, 125, 6, 2, 143, 2, 233, 2, 326, 2, 386, 2, 499, 2, 606
data 91, 125, 6, 1, 143, 1, 233, 1, 326, 1, 386, 1, 499, 1, 606
data 91, 125, 6, 2, 143, 2, 233, 1, 326, 1, 386, 1, 499, 1, 606

!User System 32
data 91, 107, 7, 3, 139, 2, 231, 2, 324, 2, 436, 0, 559, 0, 643, 0, 724
data 91, 107, 7, 4, 139, 4, 231, 3, 324, 2, 436, 2, 559, 2, 643, 1, 724
data 91, 107, 7, 5, 139, 3, 231, 1, 324, 0, 436, 0, 559, 0, 643, 0, 724
data 91, 107, 7, 0, 139, 0, 231, 0, 324, 0, 436, 0, 559, 2, 643, 2, 724
data 91, 107, 7, 2, 139, 2, 231, 1.5, 324, 1, 436, 1, 559, 2, 643, 2, 724

!User System 33
data 99, 90, 6, 2, 123, 1, 221, 1, 325, 2, 421, 1, 508, 1, 626
data 99, 90, 6, 0, 123, 0, 221, 0, 325, 6, 421, 5.5, 508, 5.5, 626
data 99, 90, 6, 0, 123, 0, 221, 0, 325, 0, 421, 0, 508, 3, 626
data 99, 90, 6, 2, 123, 1, 221, 2, 325, 4, 421, 3, 508, 2, 626

!User System 34
data 99, 89, 6, 2, 123, 2, 221, 2, 322, 2, 409, 0, 527, 0, 638
data 99, 89, 6, 7, 123, 0, 221, 0, 322, 0, 409, 0, 527, 0, 638
data 99, 89, 6, 0, 123, 0, 221, 0, 322, 6, 409, 4, 527, 4, 638
data 99, 89, 6, 1, 123, 1, 221, 1, 322, 1, 409, 1, 527, 1, 638

!User System 35
data 118, 110, 6, 4, 123, 4, 190, 4, 294, 1, 392, 1, 480, 0, 598
data 118, 110, 6, 1, 123, 1, 190, 2, 294, 1, 392, 1, 480, 1, 598

!User System 36
data 91, 107, 6, 5, 155, 4, 247, 3, 346, 1, 402, 1, 513, 3, 600
data 91, 107, 6, 7, 155, 7, 247, 7, 346, 1, 402, 1, 513, 1, 600
data 91, 107, 6, 7, 155, 3, 247, 2, 346, 1, 402, 1, 513, 1, 600
data 91, 107, 6, 2, 155, 4, 247, 2, 346, 2, 402, 2, 513, 2, 600

!User System 37
data 101, 89, 6, 4, 156, 4, 247, 2, 415, 2, 513, 2, 619, 2, 740
```

```
data 101, 89, 6, 6, 156, 6, 247, 5, 415, 5, 513, 5, 619, 3, 740
data 101, 89, 6, 2, 156, 2, 247, 2, 415, 1, 513, 1, 619, 2, 740

!User System 38
data 72, 146, 5, 4, 184, 5, 283, 6, 415, 6, 552, 6, 702
data 72, 146, 5, 4, 184, 4, 283, 6, 415, 6, 552, 6, 702
data 72, 146, 5, 4, 184, 4, 283, 4, 415, 2, 552, 2, 702
data 72, 146, 5, 4, 184, 6, 283, 6, 415, 6, 552, 6, 702
data 72, 146, 5, 4, 184, 0, 283, 0, 415, 0, 552, 0, 702
data 72, 146, 5, 6, 184, 5, 283, 2, 415, 0, 552, 0, 702
data 72, 146, 5, 6, 184, 6, 283, 7, 415, 6, 552, 2, 702
data 72, 146, 5, 0, 184, 4, 283, 6, 415, 6, 552, 6, 702
data 72, 146, 5, 3, 184, 7, 283, 7, 415, 5, 552, 5, 702

!User System 39
data 98, 110, 6, 1, 157, 0, 252, 0, 353, 0, 462, 0, 546, 0, 679
data 98, 110, 6, 1, 157, 2, 252, 2, 353, 2, 462, 2, 546, 2, 679

!User System 40
data 118, 78, 6, 0, 182, 0, 248, 3, 353, 3, 461, 3, 546, 3, 658
data 118, 78, 6, 0, 182, 0, 248, 3, 353, 3, 461, 5, 546, 5, 658
data 118, 78, 6, 1, 182, 1, 248, 1, 353, 1, 461, 3, 546, 2, 658

END PROGRAM
```

5.6.2 Program to add the best fitting linear function (204 problems over 40 systems)

The program plots S against time in days, over the reduced time domain (0 to 540 days). It then adds the best-fitting rectilinear function. The output is recovered from the screen by taking a screen shot. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements, which are the same as those of the program given in Section 5.3.1 above. They are therefore not repeated in this section (see End of program).

```
PROGRAM InterpolationAndLinearFit
dim CurrProblemDay(-20 to 1000), TotalOnDay(-20 to 1000), NumberOnDay(-20 to 1000)
clear

for i = 1 to 204
   mat CurrProblemDay = (-1)
   read AnalystKAI, UserKAI, NrReadings
   for j = 1 to NrReadings
      read Severity, Day
      let CurrProblemDay(Day) = Severity
      if j>1 then
        for k = StartDay+1 to Day-1
           let CurrProblemDay(k) = CurrProblemDay(StartDay) +
                   (k - StartDay)*(CurrProblemDay(Day) - CurrProblemDay(StartDay))/(Day
                   - StartDay)
        next k
      end if
      let StartSeverity = Severity
      let StartDay = Day
   next j

   for j = 0 to 540
      if CurrProblemDay(j) > -1 then
        let TotalOnDay(j) = TotalOnDay(j) + CurrProblemDay(j)
        let NumberOnDay(j) = NumberOnDay(j) + 1
        if NumberOnDay(j) > CMax then let CMax = NumberOnDay(j)
      end if
   next j

next i

!Linear Fitting Procedure
clear
let SumX = 0
let SumSqrX = 0
let SumY = 0
let SumXY = 0

for i = 0 to 540
  let SumX = SumX + i
  let SumSqrX = SumSqrX + i*i
  let SumY = SumY + TotalOnDay(i)/NumberOnDay(i)
```

```
  let SumXY = SumXY + i*TotalOnDay(i)/NumberOnDay(i)
next i

let MeanX = SumX/541
let MeanY = SumY/541
let m = (SumXY - SumY*SumX/541)/(SumSqrX - SumX^2/541)
let Con = MeanY - m*MeanX
let LeastSquaresSum = 0
let RegressionSquaresSum = 0
for i = 0 to 540
   let LeastSquaresSum = LeastSquaresSum + (TotalOnDay(i)/NumberOnDay(i) - m*i -
Con)^2
   let RegressionSquaresSum = RegressionSquaresSum + (MeanY - m*i - Con)^2
next i

clear
set window -100, 800, -.2, 4.8
set back "white"
set color "brown"
plot lines: 0, -1; 0, 5
for i = 1 to 5
   plot lines: -5, i; 5, i
next i

let Text$ = Trim$(Str$(CMax))
plot text, at -100, 1: Text$
plot lines: -20, 0; 565, 0
plot lines: -7, l; 540, l
for i = 0 to 540 step 30
   if i/180 = int(i/180) then
     plot lines: i, -.1;  i, .1
   else
     plot lines: i, -.05;  i, .05
   end if
next i

plot lines: -10, Con; 5, Con
plot text, at -100, Con: Trim$(Str$(Int(100*Con+.5)/100))
plot text, at 100, 4.5: "m=" & Trim$(Str$(m)) & " c=" & Trim$(Str$(Con))

set color "red"
for i = 0 to 540
   if NumberOnDay(i) > 0 then plot i, TotalOnDay(i)/NumberOnDay(i);
next i
plot
set color "green"
for i = 0 to 540
   plot i, m*i + Con
next i
plot
plot text, at 10, .5: "Regression SS: " & Trim$(Str$(RegressionSquaresSum))
plot text, at 10, .1: "Residual SS: " & Trim$(Str$(LeastSquaresSum))

!END MAIN PROGRAM
```

Data statements follow. As they are identical to the data statements of the program shown in Section 5.6.1, they are not repeated here.

```
END PROGRAM
```

5.6.3 Program to add the best fitting <u>quadratic</u> function (204 problems over 40 systems)

The program plots S against time in days, over the reduced time domain (0 to 540 days). This program requires a trial-and-error technique for the axis of symmetry, p. It returns the sum of least squares, which the user attempts to minimise, for each trial value of p. The best value for the axis of symmetry was found to be: **p = 458 days**.

The output is recovered from the screen by taking a screen shot. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements, which are the same as those of the program given in Section 5.3.1 above. They are therefore not repeated in the code below (see End of program).

```
PROGRAM InterpolationAndQuadraticFit

dim ProblemOnDay(-20 to 1000), TotalOnDay(-20 to 1000), NumberOnDay(-20 to 1000)
clear

for i = 1 to 204

  mat ProblemOnDay = (-1)
  read AnalystKAI, UserKAI, NrReadings
  for j = 1 to NrReadings
    read Severity, Day
    let ProblemOnDay(Day) = Severity
    if j>1 then
      for k = StartDay+1 to Day-1
        let ProblemOnDay(k) = ProblemOnDay(StartDay) +
                (k - StartDay)*(ProblemOnDay(Day) - ProblemOnDay(StartDay))/(Day –
                StartDay)
      next k
    end if

    let StartSeverity = Severity
    let StartDay = Day
  next j

  for j = 0 to 540
    if ProblemOnDay(j) > -1 then
      let TotalOnDay(j) = TotalOnDay(j) + ProblemOnDay(j)
      let NumberOnDay(j) = NumberOnDay(j) + 1
      if NumberOnDay(j) > CMax then let CMax = NumberOnDay(j)
    end if
  next j

next i
```

```
!Quadratic Fitting Procedure
clear
do
   input prompt "Trial value for axis of symmetry, p: ": p
   let SumX = 0
   let SumSqrX = 0
   let SumY = 0
   let SumXY = 0

   for i = 0 to 540
      let SumX = SumX + (i - p)^2
      let SumSqrX = SumSqrX + (i - p)^4
      let SumY = SumY + TotalOnDay(i)/NumberOnDay(i)
      let SumXY = SumXY + (i - p)^2*TotalOnDay(i)/NumberOnDay(i)
      let SumSqrY = SumSqrY + (TotalOnDay(i)/NumberOnDay(i))^2
   next i

   let MeanX = SumX/541
   let MeanY = SumY/541

   let a = (SumXY - SumY*SumX/541)/(SumSqrX - SumX^2/541)
   let q = MeanY - a*MeanX

   let LeastSquaresSum = 0
   let RegressionSquaresSum = 0
   for i = 0 to 540
      let LeastSquaresSum = LeastSquaresSum + (TotalOnDay(i)/NumberOnDay(i)
                    - a*(i - p)^2 - q)^2
      let RegressionSquaresSum = RegressionSquaresSum + (MeanY - a*(i - p)^2 - q)^2
   next i

   print
   print "a = "; a; "   q = "; q
   print "Least Squares Sum = "; LeastSquaresSum
   print "Another try? (Y/N): "
   print
   print
   get key: Key
   if UCase$(Chr$(Key)) = "N" then exit do

loop

clear
set window -100, 800, -.2, 4.8
set back "white"
set color "brown"
plot lines: 0, -1; 0, 5
for i = 1 to 5
   plot lines: -5, i; 5, i
next i

let Text$ = Trim$(Str$(CMax))
plot text, at -100, 1: Text$
plot lines: -20, 0; 565, 0
plot lines: -7, l; 540, l
for i = 0 to 540 step 30
   if i/180 = int(i/180) then
      plot lines: i, -.1;  i, .1
   else
```

```
      plot lines: i, -.05;  i, .05
   end if
next i

set color "red"
for i = 0 to 540
   if NumberOnDay(i) > 0 then plot i, TotalOnDay(i)/NumberOnDay(i);
next i
plot

set color "green"
for i = 0 to 540
   plot i, a*(i - p)^2 + q
next i
plot

let Con = a*p*p + q
plot lines: -10, Con; 5, Con
plot text, at -100, Con: Trim$(Str$(Int(100*Con+.5)/100))
plot text, at 100, 4.5: "a=" & Trim$(Str$(Con)) & " p=" & Trim$(Str$(p)) & " q=" &
Trim$(Str$(q))

plot text, at 10, .5: "Regression SS: " & Trim$(Str$(RegressionSquaresSum))
plot text, at 10, .1: "Residual SS: " & Trim$(Str$(LeastSquaresSum))

!END MAIN PROGRAM CODING
```

Data statements follow. As they are identical to the data statements of the program shown in Section 5.6.1, they are not repeated here.

```
END PROGRAM
```

5.6.4 Program to graph the best fitting <u>reciprocal</u> function (204 problems over 40 systems)

The program plots S against time in days, over the reduced time domain (0 to 540 days). This program requires a trial-and-error technique for the vertical asymptote, a. It returns the sum of least squares, which the user attempts to minimise, for each trial value of a. The best value for this constant was found to be: **a = 58 days**.

The output is recovered from the screen by taking a screen shot. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements, which are the same as those of the program given in Section 5.3.1 above. They are therefore not repeated in the code below (see End of program).

```
PROGRAM InterpolationAndReciprocalFit

dim ProblemOnDay(-20 to 1000), TotalOnDay(-20 to 1000), NumberOnDay(-20 to 1000)
clear

for i = 1 to 204

   mat ProblemOnDay = (-1)
   read AnalystKAI, UserKAI, NrReadings
   for j = 1 to NrReadings
      read Severity, Day
      let ProblemOnDay(Day) = Severity
      if j>1 then
        for k = StartDay+1 to Day-1
           let ProblemOnDay(k) = ProblemOnDay(StartDay) + (k –
                   StartDay)*(ProblemOnDay(Day) –
                   ProblemOnDay(StartDay))/(Day - StartDay)
        next k
      end if

      let StartSeverity = Severity
      let StartDay = Day
   next j

   for j = 0 to 540
      if ProblemOnDay(j) > -1 then
        let TotalOnDay(j) = TotalOnDay(j) + ProblemOnDay(j)
        let NumberOnDay(j) = NumberOnDay(j) + 1
        if NumberOnDay(j) > CMax then let CMax = NumberOnDay(j)
      end if
   next j

next i


!Reciprocal Fitting Procedure
clear
```

```
do
   input prompt "Trial value for quasi vertical asymptote, a: ": a
   let SumX = 0
   let SumSqrX = 0
   let SumY = 0
   let SumXY = 0

   for i = 0 to 540
      let SumX = SumX + 1/(i + a)
      let SumSqrX = SumSqrX + 1/(i + a)^2
      let SumY = SumY + TotalOnDay(i)/NumberOnDay(i)
      let SumXY = SumXY + 1/(i + a)*TotalOnDay(i)/NumberOnDay(i)
   next i

   let MeanX = SumX/541
   let MeanY = SumY/541

   let k = (SumXY - SumY*SumX/541)/(SumSqrX - SumX^2/541)
   let l = MeanY - k*MeanX

   let LeastSquaresSum = 0
   let RegressionSquaresSum = 0
   for i = 0 to 540
      let LeastSquaresSum = LeastSquaresSum + (TotalOnDay(i)/NumberOnDay(i) –
          k/(i + a) - l)^2
      let RegressionSquaresSum = RegressionSquaresSum + (MeanY - k/(i + a) - l)^2
   next i

   print
   print "a = "; a; "   k = "; k; "  l = "; l
   print "Least Squares Sum = "; LeastSquaresSum
   print "Another try? (Y/N): "
   print
   print
   get key: Key
   if UCase$(Chr$(Key)) = "N" then exit do

loop

clear
set window -100, 800, -.2, 4.8
set back "white"
set color "brown"
plot lines: 0, -1; 0, 5
for i = 1 to 5
   plot lines: -5, i; 5, i
next i

let Text$ = Trim$(Str$(CMax))
plot text, at -100, 1: Text$
plot lines: -20, 0; 565, 0
plot lines: -7, l; 540, l
for i = 0 to 540 step 30
   if i/180 = int(i/180) then
      plot lines: i, -.1;  i, .1
   else
      plot lines: i, -.05;  i, .05
   end if
next i
```

```
let Con = k/a + l
plot lines: -10, Con; 5, Con
plot text, at -100, Con: Trim$(Str$(Int(100*Con+.5)/100))
plot text, at 100, 4.5: "a=" & Trim$(Str$(a)) & " k=" & Trim$(Str$(k)) & " l=" & Trim$(Str$(l))

set color "red"
for i = 0 to 540
   if NumberOnDay(i) > 0 then plot i, TotalOnDay(i)/NumberOnDay(i);
next i
plot

set color "green"
for i = 0 to 540
   plot i, k/(i + a) + l
next i
plot

plot text, at 10, .4: "Regression SS: " & Trim$(Str$(RegressionSquaresSum))
plot text, at 10, .1: "Residual SS: " & Trim$(Str$(LeastSquaresSum))

!END MAIN PROGRAM CODING
```

Data statements follow. As they are identical to the data statements of the program shown in Section 5.6.1, they are not repeated here.

```
END PROGRAM
```

5.6.5 Program to add the best fitting exponential decay function (204 problems over 40 systems)

The program plots S against time in days, over the reduced time domain (0 to 540 days). This program requires a trial-and-error technique for the exponential constant, k. It returns the sum of least squares, which the user attempts to minimise, for each trial value of k. The best value for this constant was found to be: **k = -0.01038**.

The output is recovered from the screen by taking a screen shot. For full explanation of the programming statements, see Kemeny & Kurtz (1985) and Giordano (1997). This program contains its own data as **Data** statements, which are the same as those of the program given in Section 5.3.1 above. They are therefore not repeated in the code below (see End of program).

```
PROGRAM InterpolationAndExponentialFit

dim CurrProblemOnDay(-20 to 1000), TotalOnDay(-20 to 1000), NumberOnDay(-20 to 1000)
clear

for i = 1 to 204

  mat CurrProblemOnDay = (-1)
  read AnalystKAI, UserKAI, NrReadings
  for j = 1 to NrReadings
    read Severity, Day
    let CurrProblemOnDay(Day) = Severity
    if j>1 then
      for k = StartDay+1 to Day-1
        let CurrProblemOnDay(k) = CurrProblemOnDay(StartDay) +
              (k - StartDay)*(CurrProblemOnDay(Day) -
              CurrProblemOnDay(StartDay))/(Day - StartDay)
      next k
    end if

    let StartSeverity = Severity
    let StartDay = Day
  next j

  for j = 0 to 540
    if CurrProblemOnDay(j) > -1 then
      let TotalOnDay(j) = TotalOnDay(j) + CurrProblemOnDay(j)
      let NumberOnDay(j) = NumberOnDay(j) + 1
      if NumberOnDay(j) > CMax then let CMax = NumberOnDay(j)
    end if
  next j

next i

!Exponential Fitting Procedure
clear
do
```

```
   input prompt "Trial value for k: ": k
   let SumX = 0
   let SumSqrX = 0
   let SumY = 0
   let SumXY = 0

   for i = 0 to 540
      let SumX = SumX + Exp(k*i)
      let SumSqrX = SumSqrX + Exp(2*k*i)
      let SumY = SumY + TotalOnDay(i)/NumberOnDay(i)
      let SumXY = SumXY + Exp(k*i)*TotalOnDay(i)/NumberOnDay(i)
   next i

   let MeanX = SumX/541
   let MeanY = SumY/541

   let Con = (SumXY - SumY*SumX/541)/(SumSqrX - SumX^2/541)
   let l = MeanY - Con*MeanX

   let LeastSquaresSum = 0
   let RegressionSquaresSum = 0
   for i = 0 to 540
      let LeastSquaresSum = LeastSquaresSum + (TotalOnDay(i)/NumberOnDay(i) –
          Con*Exp(k*i) - l)^2
      let RegressionSquaresSum = RegressionSquaresSum + (MeanY - Con*Exp(k*i) - l)^2
   next i

   print
   print "C = "; Con; "   l = "; l
   print "LSS = "; LeastSquaresSum
   print "Another try? (Y/N): "
   print
   print
   get key: Key
   if UCase$(Chr$(Key)) = "N" then exit do

loop

clear
set window -100, 800, -.2, 4.8
set back "white"
set color "brown"
plot lines: 0, -1; 0, 5
for i = 1 to 5
   plot lines: -5, i; 5, i
next i

let Text$ = Trim$(Str$(CMax))
plot text, at -100, 1: Text$
plot lines: -20, 0; 565, 0
plot lines: -7, l; 540, l
for i = 0 to 540 step 30
   if i/180 = int(i/180) then
     plot lines: i, -.1;  i, .1
   else
     plot lines: i, -.05;  i, .05
   end if
next i
```

```
set color "red"
for i = 0 to 540
   if NumberOnDay(i) > 0 then plot i, TotalOnDay(i)/NumberOnDay(i);
next i
plot

set color "green"
for i = 0 to 540
   plot i, Con*Exp(k*i) + l
next i
plot
plot lines: -10, Con + l; 5, Con + l
plot text, at -100, Con + l: Trim$(Str$(Int(100*(Con + l)+.5)/100))
plot text, at 100, 4.5: "C=" & Trim$(Str$(Con)) & " k=" & Trim$(Str$(k)) & " l=" & Trim$(Str$(l))

plot text, at ix+10, .1: "Residual SS: " & Trim$(Str$(LeastSquaresSum))
plot text, at ix+10, .4: "Regression SS: " & Trim$(Str$(RegressionSquaresSum))

!END MAIN PROGRAM CODING
```

Data statements follow. As they are identical to the data statements of the program shown in Section 5.6.1, they are not repeated here.

```
END PROGRAM
```

Appendix 6.1

Machines and the basic laws of physics which govern them

The American Heritage® Dictionary (2004) defines a machine as:

> " A device consisting of fixed and moving parts that modifies mechanical energy and transmits it in a more useful form."

The same reference includes the following examples:

> " A system or device, such as a computer, that performs or assists in the performance of a human task"; and

> " An intricate natural system or organism, such as the human body."

Wikipedia® (2005) defines a **machine** as:

> " Any mechanical or organic device that transmits or modifies energy to perform or assist in the performance of tasks."

They note, however that modern power tools, automated machine tools, and human-operated power machinery complicate their definition.

As a computer-based system comes within the above definitions of a machine, the laws of physics covering machines in general must apply to computer systems. However, a completely deterministic treatment of information systems based solely on the known laws of physics would be naïve in the light of the above 'complication' noted by the reference. What this study sort to do rather was to find parallels within the physical understanding of machines to redefine IS terms as metaphoric counterparts (see Chapter 6, Sections 6.3 and 6.3.1). Some of these might be physics-based, while others are purely analogical.

The operation of machines is governed by five general laws of physics: Newton's three laws of *motion* and the first and second laws of *thermodynamics* (Wikipedia® 2005). According to these, the parts of any machine exhibit *inertia*, or resistance to a change in their state of rest or rectilinear velocity. A net force applied to a machine part will be opposed by an equal but opposite force. This inertial behaviour by its parts dictates that more energy is required to set a machine in operation than to maintain it in operation (Wikipedia® 2005).

The laws of thermodynamics rule out the possibilities:

(a) of obtaining more work from a machine than the equivalent energy put in to it; and

(b) of having non-inertial resistance to the energy input, which means that not all the energy input is available for doing useful work. Resistance to motion such as friction is always present to some extent. Friction itself cannot cause motion, but can oppose motion brought about by other forces. This it does by generating a force opposing the motion up to a maximum, beyond which friction is overcome. The inescapable presence of friction means that no machine can run on its own perpetually. This applies even if no useful work is drawn from it (Wikipedia, 2005).

Wikipedia® (2005) also describes the *inefficiency* of a machine as:

> " The degree or percentage to which a machine does not accomplish the work it could do without the restrictions of friction."

From the above, the following can be deduced:

1) A motivating net force is opposed in two ways; by the inertia of bodies and by other forms of resistance, such as friction. Inertia responds to a motivating force by an equal but opposite reactionary force. The body responds to a net force in a predictable way, accelerating as described by Newton's Second Law of Motion.

2) Friction responds to a net force by applying an equal but opposite force but only up to a certain maximum. If this maximum is less than the net motivating force, the body accelerates in the direction of the force. If it is greater than the net force, the body remains at rest or decelerates. If the forces balance, the body will either remain at rest or continue with a constant, rectilinear velocity.

3) The previous two factors dictate that it requires more energy, applied by way of motivating net forces, to start a machine in operation than to keep it running.

4) Some friction is always present, so no machine will run perpetually without a continued energy input, even if it does no work on the external environment.