# Theorizing the Use of Multiple Conceptual Models in Combination

*Full Research*

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## Abstract

*Conceptual modelling continues to be an important means for graphically capturing the requirements of an information system. Observations of modelling practice suggest that modellers often use multiple conceptual models in combination, because they articulate different aspects of real-world domains. Yet, the available empirical as well as theoretical research in this area has largely studied the use of single models, or single modelling grammars. We develop a Theory of Combined Ontological Coverage by extending an existing theory of ontological expressiveness of conceptual modelling grammars. Our new theory posits that multiple conceptual models are used to increase the maximum coverage of the real-world domain being modelled, whilst trying to minimize the ontological overlap between the models. We illustrate how the theory can be applied to analyse sets of conceptual models. We develop three propositions of the theory about evaluations of model combinations in terms of users' selection, understandability and usefulness of conceptual models.*

### Keywords

Conceptual modelling, representation theory, maximum ontological completeness, minimal ontological overlap, theory development, model selection, model understanding, model usefulness.

## INTRODUCTION

When analysing or designing information systems, information system professionals such as systems analysts, workflow engineers, process managers or information technology (IT) managers frequently develop and use representations of the relevant features of a real-world domain. They do this to with two primary goals in mind (Fettke 2009): to facilitate communication about the relevant real-world domain amongst the different stakeholders involved in an information systems project, and to document the existing or future system to allow for operation, maintenance, improvement or training. These representations are called conceptual models because they represent someone's or some group's understanding of a real-world domain and the relevant features or phenomena within (Mylopoulos 1992).

Conceptual models are developed using grammars, i.e., sets of constructs and rules to combine these constructs (Wand and Weber 2002). For example, entity-relationship diagrams (Chen 1976) can be used to specify real-world domain in terms of the entities that make up that domain, the attributes that characterize these entities, and the relationships that may exist between the entities. Process modelling grammars such as the Business Process Model and Notation (BPMN, OMG 2011), conversely, can be used to specify real-world domains in terms of occurring events and the activities that can be triggered and executed in response to these events.

Many different conceptual modelling grammars have been proposed and applied in practice over time, to the point that the terms "yet/not another modelling approach (YAMA/NAMA)" were coined (Siau 2004). In practice, empirical studies report varying levels and extents of usage of different modelling grammars and models (Davies et al. 2006; Fettke 2009), but it would appear that models developed using grammars such as Entity-Relationship Diagrams (ERD), Unified Modelling Language (UML) and others remain popular and their usage stable over time.

Importantly, empirical studies clearly indicate that IS professionals typically do not use just one conceptual model for their analysis and design tasks. Instead, the evidence suggests that usually *multiple* models designed using different grammars are used in combination. For example, Recker (2012) reported that over 30% of surveyed process modellers access additional grammars when modelling business processes. Green et al. (2011) showed that 80% of users of modelling tool environments select and use multiple grammars in combination when engaging in conceptual modelling. Likewise, some of the most popular modelling methods in use, such as UML or BPMN, offer the possibility of creating different types of models that users can choose from. UML, for example, provides grammars to model class diagrams, activity diagrams or statecharts to name just a few

(Rumbaugh, Jacobson and Booch 2004). Practitioner surveys show that many of these diagram types are used together (Dobing and Parsons 2008). Likewise, longstanding methodologies such as Multiview (Avison and Wood-Harper 1986) have promoted the use of multiple models for close to thirty years.

Surprisingly, whilst conceptual modelling is an active research area in information systems (Wand and Weber 2002; Burton-Jones, Wand and Weber 2009; Siau and Rossi 2011), this research is almost exclusively focused on *single* models or grammars: research has explored how useful a grammar may be for creating a model (Recker et al. 2011), or how much domain understanding can be created from reading a model (Bera, Burton-Jones and Wand 2014) or how additional notation elements such as colours can enhance a model (Masri, Parker and Gemino 2008). By contrast, research on the use of *multiple* grammars (Green et al. 2011) let alone *multiple* types of models (Siau and Lee 2004) is very sparse.

In this paper, therefore, we extend an existing theory on the ontological expressiveness of conceptual modelling grammars (Wand and Weber 1990, 1993, 1995; Weber 1997) to develop a new theory to analyse, explain and predict the *use of multiple conceptual models in combination*. Our theory utilizes two principles, maximum ontological completeness and minimum ontological overlap, to describe which model combinations are purposeful, that is preferred, beneficial and useful for users. We then show how our new theory can be used to analyse different types of conceptual models and how it can be used also to derive predictions about consequences from using multiple models in combination. We outline implications regarding three important decisions in the use of multiple models: *selecting* which models to use, determining how much *understanding* can be derived from multiple models, and explaining the *usefulness* of multiple conceptual models.

We proceed as follows: first, we will review related research on the use of multiple conceptual models and recap the selected theoretical foundation. Then we will formulate our new theory and develop its key propositions. Next, we will illustrate our theory in an analysis of different conceptual models from a case published in a leading textbook (Whiteley 2013). Finally, we propose a range of implications and provide a brief conclusion.

## BACKGROUND

### Research on the Use of Multiple Conceptual Models

When we argue that conceptual modelling research is largely focused on single elements in isolation, we do not wish to say that no research on the use of multiple conceptual modelling elements has been performed. Table 1 provides a summary of elated research achievements.

Table 1. Relevant Literature on the Usage of Multiple Conceptual Models

| Reference | Type of study | Object of study | Summary of Research and Findings |
|---|---|---|---|
| Siau and Lee (2004) | Empirical | Use of class diagrams and use case diagrams in UML | The research shows that use case diagrams and class diagrams depict different aspects of a problem domain. To users, the models appear to have very little overlap in the information captured, and both are perceived as necessary in requirements analysis. |
| Dobing and Parsons (2008) | Empirical | Use of UML diagram types | Modelling practitioners use multiple, different types of UML diagrams in most projects. More than 50% of users report that they use five or more different diagram types in at least a third of their software development projects. |
| Gemino and Parker (2009) | Empirical | Use of textual use cases together with use case diagrams. | The research shows that participants that receive supporting diagrams developed higher levels of domain understanding than with a textual use case description alone. |
| Fettke (2009) | Empirical | Use of conceptual modelling in practice | The survey shows that modelling practitioners typically do not use one but several modelling grammars in combination Almost all modelling grammars complement each other but correlations suggest that certain grammars complement other grammars better than others (e.g., Event-driven Process Chains with ERD but not UML). |

| | | | |
|---|---|---|---|
| Recker (2012) | Empirical | Use of modelling tools | The study shows that 31.4% of surveyed modellers use additional grammars when modelling if this functionality is offered by the tool. Users that use multiple grammars report significantly higher levels of perceived usefulness. |
| Recker and Mendling (2006) | Theoretical | Two process modelling grammars | The paper analyses whether models developed in one conceptual grammar can be readily translated to another, executable grammar, thereby identifying model elements for which a translation cannot readily be achieved. |
| Green et al. (2007) | Theoretical | Multiple interoperability standards | The paper analyses multiple standards to define systems interoperability, and examined which combinations of standards can theoretically achieve best coverage. |
| zur Muehlen and Indulska (2010) | Theoretical | Process and business rule modelling grammars | The paper develops predictions about which combinations of process modelling and business rule modelling grammars should be used in combination. |
| Green et al. (2011) | Theoretical and empirical | Selection of multiple grammars | The study examines which grammars available in a modelling tool are selected by users in which sequence. The results show that users select multiple grammars to overcome construct deficit, and select from a predicted subset of grammars only. |

We can identify several conclusions from this review. First, empirical surveys have shown that indeed practitioners often use multiple models (Dobing and Parsons 2008; Fettke 2009; Recker 2012). Second, there is also evidence to suggest that using multiple models has benefits over the use of single models, for instance, in enabling a more complete understanding of the modelled domain (Gemino and Parker 2009) – if the models do not have much overlap in information between them (Siau and Lee 2004). Third, we also note that even though evidence suggests *that* multiple models may be preferred and may have benefits (Dobing and Parsons 2008), we do not yet have an understanding *how* and *why* that is. Forth, work that builds on predominant theory of conceptual modelling based on ontology (Burton-Jones and Weber 2014) has not yet devoted much attention to the use of multiple models – neither theoretically, analytically nor empirically. However, foreshadowing the theoretical foundation below, we see that some early work has been done on analysing *grammar* combinations (Recker and Mendling 2006; Green et al. 2007; zur Muehlen and Indulska 2010) but not *model* combinations. Moreover, all but one study (Green et al. 2011) have been non-empirical in nature. Therefore, there remains a need to (a) formulate a theoretical explanation for how, why and which model combinations may be useful for users, and (b) empirically evaluate these predictions.

**Theoretical Foundation**

Much of the current research on conceptual modelling is based on a theory originally formulated by Wand and Weber (1990, 1993). Their so-called representation theory set out to address the question of how well conceptual modelling grammars can generate faithful models of relevant real-world phenomena (Burton-Jones and Weber 2014).

The theory purports to account for variations in the ability of conceptual modellers to develop models of real-world phenomena that are complete and clear. To do so, it builds upon an ontological model of an information system derived from a philosophical ontology developed by Bunge (1977, 1979) and suggests a mapping between the set of constructs existent in a conceptual modelling grammar available to the user to model aspects of the real world, and the set of constructs in the ontology that are required and sufficient to describe various real-world phenomena. Based on this mapping, theory identifies four types of ontological deficiencies that can exist in a modelling grammar or in a model developed with a grammar (Wand and Weber 1993):

1. *Construct deficit*: An ontological construct exists that has no mapping from any modelling construct (a 1:0 mapping).
2. *Construct redundancy*: Two or more modelling constructs map to a single ontological construct (a 1:m mapping).
3. *Construct overload*: A single modelling construct maps to two or more ontological constructs (a m:1 mapping).
4. *Construct excess*: A modelling construct does not map onto any ontological construct (a 0:1 mapping).

Wand and Weber (1993) structured these deficiencies using two basic criteria, viz., ontological completeness and ontological clarity. A good modelling grammar (or a good model) should be ontologically complete (viz., exhibit minimal construct deficit) as well as ontologically clear (viz., exhibit minimal construct overload, redundancy, and excess) to allow users to unambiguously describe all required real-world phenomena in a selected business domain the information system is intended to support.

This theory has over time been subjected to various tests to examine the predictions of ontological completeness and clarity on modellers' ability to develop faithful models of real-world phenomena. Structured overviews of these studies are provided by Green et al. (2011) and Saghafi and Wand (2014), amongst others. A meta-analysis of empirical studies to date shows that the theory indeed is able to make largely valid predictions about the use of conceptual modelling in practice (Saghafi and Wand 2014). However, with a few noted exceptions (see Table 1), the research has been on *single* grammars or *single* models, examining questions such as how useful a grammar might be (Recker et al. 2011), or whether the existence of ontological deficiencies in a grammar inhibit users' ability to faithfully model a particular real-world phenomenon (e.g., Bodart et al. 2001; Shanks et al. 2008; Parsons 2011).

One might argue that the lack of focus on multiple conceptual modelling elements is due to a boundary condition of the theory in that it offers predictions only about elements in isolation. However, Weber (1997, pp. 100-102) already noted that the theory also provides logic o generate predictions about the use of modelling grammars in combination, namely to offset ontological deficiencies (namely, construct deficit) in any one grammar. Green (1996) operationalized this conjecture on the basis of two principles:

1. When multiple grammars are chosen to represent real-world phenomena, users will select a combination with *maximum ontological completeness (MOC)*, that is, a combination of grammars that minimizes total construct deficit and thus covers as many real-world phenomena as possible.
2. Users will also select grammar combinations with *minimum ontological overlap (MOO)*, that is, a combination of grammars that minimizes the number of real-world phenomena that can be modelled via both grammars.

These two principles, notably, have been applied in studies that set out to develop propositions about which grammar combinations will be selected by users for particular purposes, say, to implement systems interoperability (Green et al. 2007) or to integrate business rules with process models (zur Muehlen and Indulska 2010). Table 1 provides an overview of relevant applications. Interestingly, however, the theory has not yet been extended to examine combinations of conceptual models, rather than grammars, which is what we set out to achieve in this paper.

## A THEORY OF USING MULTIPLE CONCEPTUAL MODELS IN COMBINATION

### Description of the Theory of Combined Ontological Coverage

Which models may be purposeful to combine for use when trying to develop representations of some focal real-world phenomena? In answering this question we first delineate what we mean by *model users* and their *purposeful use of conceptual models*. With model users we refer not to those individuals that develop conceptual models (i.e., model creators or modelers, see Gemino and Wand 2004) but to those individuals that apply models in support of their analysis and design tasks (called model interpretators or model readers, see Gemino and Wand 2004).

We recognize that model use occurs as part of a particular task at hand that is characterized by a task goal. This might be, for instance, the task of identifying system requirements from a domain model with the goal of expressing relevant functional requirements completely and clearly. Therefore, model use is a means to an end. The tasks and task goals may vary. For instance, Wand and Weber (Wand and Weber 2002, p. 363) described at least four application tasks for conceptual modelling. Still, the use of a model by a person applying the model for a task will be evaluated in light of how well it allows the user to accomplish the particular task (Recker and Rosemann 2010). Therefore, we can evaluate purposeful use of models in at least three ways:

1. Prior to engaging in model-based tasks, we can evaluate users' expectations about perceived performance gains that will stem from the use of conceptual models for a particular task. These expectations could be captured as beliefs about perceived performance expectancies about the grammar for a model-use task (Recker and Rosemann 2010), but they will also manifest in actual behaviours, more precisely, in the *selection decision* about which model combinations to use for a given task.
2. During the engagement in model-based tasks, we can evaluate whether and how many performance gains stem from the use of conceptual models. The use of conceptual models in our understanding primarily

involves reading the model to construct knowledge about the depicted domain (Gemino and Wand 2003), and therefore the evaluation of performance must be how much *domain understanding* can be learned from using conceptual models (Gemino and Wand 2004; Burton-Jones, Wand and Weber 2009).

3. After engaging in model-based tasks, we can evaluate user's reported performance gains that stemmed from the use of conceptual models for a particular task. These gains can be captured as beliefs about perceived performance experiences and thus can be measured as the *perceived usefulness* of a model combination to support the tasks at hand (Recker and Rosemann 2010).

The primary conjecture of our theory is therefore that model users' *selection* of multiple models, their development of *domain understanding* from their use of multiple models, and the *perceived usefulness* of multiple models will be dependent on the models' *combined completeness* and *clarity* of representation of the focal real-world phenomena. This is because the primary aim for the use of conceptual models – in isolation or in combination – remains to obtain a complete and clear representation of real-world phenomena of relevance. The evidence collected to date indeed shows that domain understanding improves when these ontological rules are followed in a model (Saghafi and Wand 2014).

Therefore, in analogy with the arguments by Weber (1997) and Green (1996) we predict, first, that users will select, use, and enhance their performance in constructing knowledge from a model, when model combinations are chosen that together cover as large a representation of the focal real-world phenomena as possible (*the MOC hypothesis*). Second, we predict that the choice of model combinations will also be motivated by a desire for parsimony, that is, a combination of models that minimizes an overlap of real-world phenomena representations between them (*the MOO hypothesis*). Figure 1 illustrates these two key premises visually.

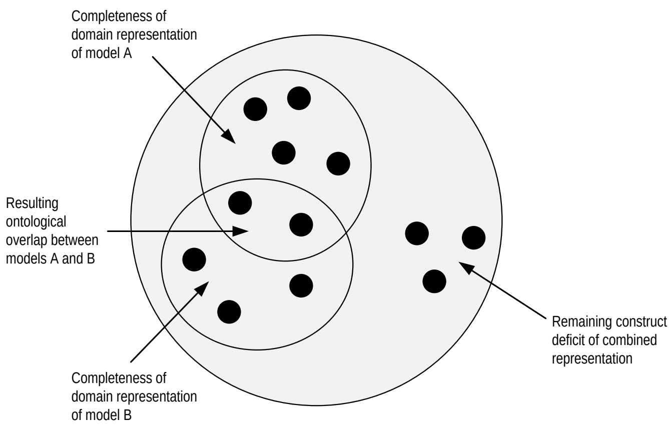



Figure 1: Illustration of Key Theory Premises, in analogy to Weber (1997, p. 102)

We make two notes about this theory. First, we deviate from Weber (1997) and Green (1996) on two important accounts: first, they argue that the MOC and MOO hypotheses guide which grammars for modelling are being chosen by users for modelling. We, however, argue that it is not the grammar and their *potential* maximum coverage of real-world phenomena that matters but the *actual* maximum coverage of real-world phenomena that is available in any combination of models produced by a grammar, or indeed by multiple grammars. In consequence, users may choose model combinations that are produced by one grammar only, or model combinations that include models generated from different grammars. Second, we note that their original theory purported to explain the choice of grammars for model *creation* purposes, whereas we now develop a theory for the choice of models for model *interpretation* (Gemino and Wand 2004).

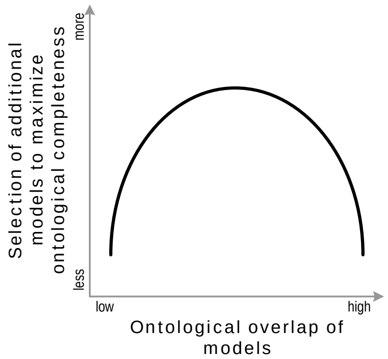
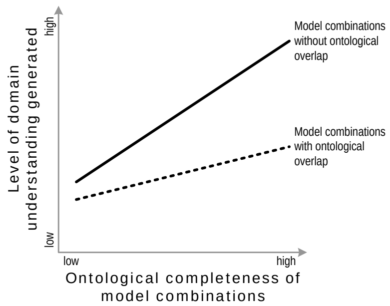
Second, we note that the two premises, the MOC and MOO hypotheses, may at times be in conflict. For instance, it is conceivable that a combination of models that maximizes the representation of real-world phenomena also shares a large set of presentation constructs, viz., has a high level of ontological overlap. Imagine a second model combination that has lower levels of combined representation of real-world phenomena but also lower levels of ontological overlap between the models. The question arises which of these two combinations will then be selected, used or deemed more useful. This is not a trivial question. Green (1996) argues that the primary objective of grammar selection is MOC. But is that true for the selection and use of models, or could it be that model use is governed by a principles of clarity over completeness? There is some evidence that suggests that the simplicity of a representation may be more useful than its completeness. For instance, Siau and Lee (2004) showed that users preferred easier to use diagrams and that these enabled them to obtain a more complete representation. Zur Muehlen et al. (2007) showed that users often compromise completeness to obtain a more simple model, presumably to aid interpretation more.

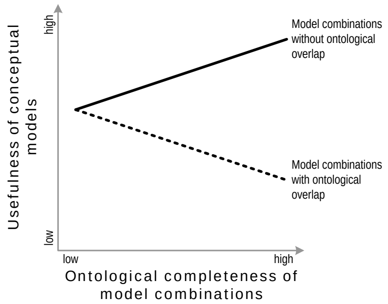
To examine the primacy of the two hypotheses against each other, and also to evaluate the abovementioned deviations in our theoretical account from the original predictions offered by Weber (1997) and Green (1996), empirical evaluation will be required. To facilitate such research, therefore, we will now generate a set of three testable models in the form of propositions.

### Proposition Development

To demonstrate falsifiability of the Theory of Ontological Coverage, we now examine how the proposed theoretical properties of model combinations relate to empirical matters. To that end, we develop three propositions that provide illustrations how the theory might manifest empirically. Table 2 summarizes three exemplary propositions that we derive from our theory in regards to the three described evaluations of the purposeful use of conceptual models in combination. Table 2 provides illustrations of expected effects together with explanations for the predictions. In turn, Table 2 provides examples of three testable models that provide clear expectations and guidance for researchers to contrast against empirical data that could and should be collected to examine our theory.

Table 2. Summary of Theory Propositions

<table>
<tr><th>Outcome</th><th>Illustration</th><th>Explanation of Effect</th></tr>
<tr><td>Selection of conceptual models</td><td>
</td><td>The decision which conceptual models will be selected together from a set of available models to form a representation of some focal-real world phenomena will primarily be a function of the desired ontological completeness of the combined representation. From a starting model, additional models will be selected with the view to maximize completeness ontological because users have a desire to compensate for impoverished representations (see also the discussion of adaptive behaviors by Weber 1997, pp. 95-96). In doing so, the ontological overlap between the sets of models will also increase. We predict that users will select additional models until a particular level of overlap has been achieved that they perceive to be bearable. Should this level of overlap be exceeded, we predict that users will de-select models and in turn, lower the achieved MOC because otherwise the domain representation achieved will be undermined by lack of clarity and would require too much cognitive load when interpreting the models.</td></tr>
<tr><td>Domain understanding</td><td>
</td><td>The level of domain understanding that can be generated from reading (or rather, learning, see Gemino and Wand 2003) a set of models will be a function of the ontological completeness of the selected model combination. This is because the more elements of a domain that are represented in a conceptual model of the domain, the more information is available for assimilation into the users' mental model about all relevant aspect of focal real-world phenomena. The level of domain understanding that can be achieved from a selected set of models will be moderated by the level of ontological overlap between the selected models. Model combinations with higher levels of ontological overlap will introduce additional extraneous conditional load (Gemino and Wand 2005), in turn diminishing the capacity to absorb more information and hence the ability to learn more domain understanding.</td></tr>
</table>

| | | |
|---|---|---|
| Usefulness of conceptual model combinations |  | Perceptions of usefulness of model combinations will increase when ontological completeness of the achieved representation will increase. This is because evaluations of the usefulness for a model-based task will be dependent on users having manifestations of relevant real-world phenomena explicit in a model. If there are deficits of desired representations, model users are likely not to find the models useful (Recker et al. 2011). However, model combinations with increased ontological completeness and increased ontological overlap will be evaluated as less useful, because the additional added complexity of the representation will undermine the gains in representational coverage, in turn making the model combination less useful than a less complex, less complete combination. |

## ILLUSTRATION OF THE THEORY

We now give a simple example of the application of the theory to the study of the use of multiple models from one illustrative domain. Similar to other studies of conceptual modelling (e.g., Siau and Lee 2004; Shanks et al. 2008) we peruse a case drawn from an established textbook – in our case, the High Peak Bicycles case described in (Whiteley 2013, pp. 228-263), simply because the textbook features a wide selection of different models for this case. The case describes the composition of an information system to maintain records of bicycle rentals, with requirements that the systems allows maintaining a bike register, renting out and returning rents, allocating bikes, processing transactions and other functionality. For reasons of scope, we focus specifically on four diagram types, viz., use case, entity-relationship, data flow and sequence diagram (see Figure 2). We selected these models as each of them had previously been analysed using the ontological constructs inherent to representation theory (Wand and Weber 1993; Irwin and Turk 2005; Siau 2010; Green et al. 2011).

Which combination of models would now be selected and used by users to complete system analysis and design tasks? Wand and Weber's (1993) original theory allows us to examine whether ontological completeness or clarity is deficient in any *one* of the different models. Our theory now allows us to speculate about the combined ontological coverage of different combinations of these models. For reasons of scope, we have to limit our analysis here to some general observations without providing much rationale for the underlying representation mappings (Wand and Weber 1993), overlap analysis procedures (Green et al. 2011), or indeed the semantics of the model grammars themselves. Relevant information about the grammars is available in most textbooks (e.g., Yourdon 1989; Fowler 2004; Whiteley 2013). Nonetheless, in our view the following points still testify to the explanatory power and fertility of the proposed theory:

1. We note that use case, sequence and entity-relationship diagrams together achieve the highest level of ontological completeness. For instance, the use case diagram contains representations for *things* (the actors). The *classes* of these things, their *properties* and *interactions* are represented in the entity-relationship diagram. Finally, the sequence diagram provides representations of the *states* of these things, the *events* that represent occurrences that change the states of these things, and the *transition laws* that govern the state changes.
2. We note that a potential addition of data flow diagram to this combination would not increase ontological completeness but instead only increase ontological overlap. This is because the representations in this diagram (e.g., *class* [data store, entity], *state* [flowline], *event* [entity->data flow->process]) are already provided through representations available in the other models.
3. Our theory predicts that users will select from the set of diagrams in the following order: first, use case diagram and entity-relationship diagram (because this combination has an increase in ontological completeness that is accompanied by the lowest increase in ontological overlap); second, sequence diagram (because it increases ontological completeness at the smaller expense of ontological overlap than the data flow diagram). Third, should the data flow diagram also be selected, the theory predicts that users will un-select this diagram from the combination in order to decrease the level of ontological overlap.

## IMPLICATIONS AND CONCLUSIONS

Conceptual models that aid the analysis and design of information systems are rarely ever used in isolation. We propose a theory that can be used to examine which combinations of conceptual models are purposeful for users to develop an understanding of relevant real-world domain relevant to them. We demonstrated how a theory founded in principles of maximum ontological completeness and minimal ontological overlap of conceptual models can guide the selection, use and evaluation of different types of conceptual models. We described three propositions of the new theory including explanations of the expected effects. We also briefly showed an application of the theory in the study of different models of a bicycle rental domain.

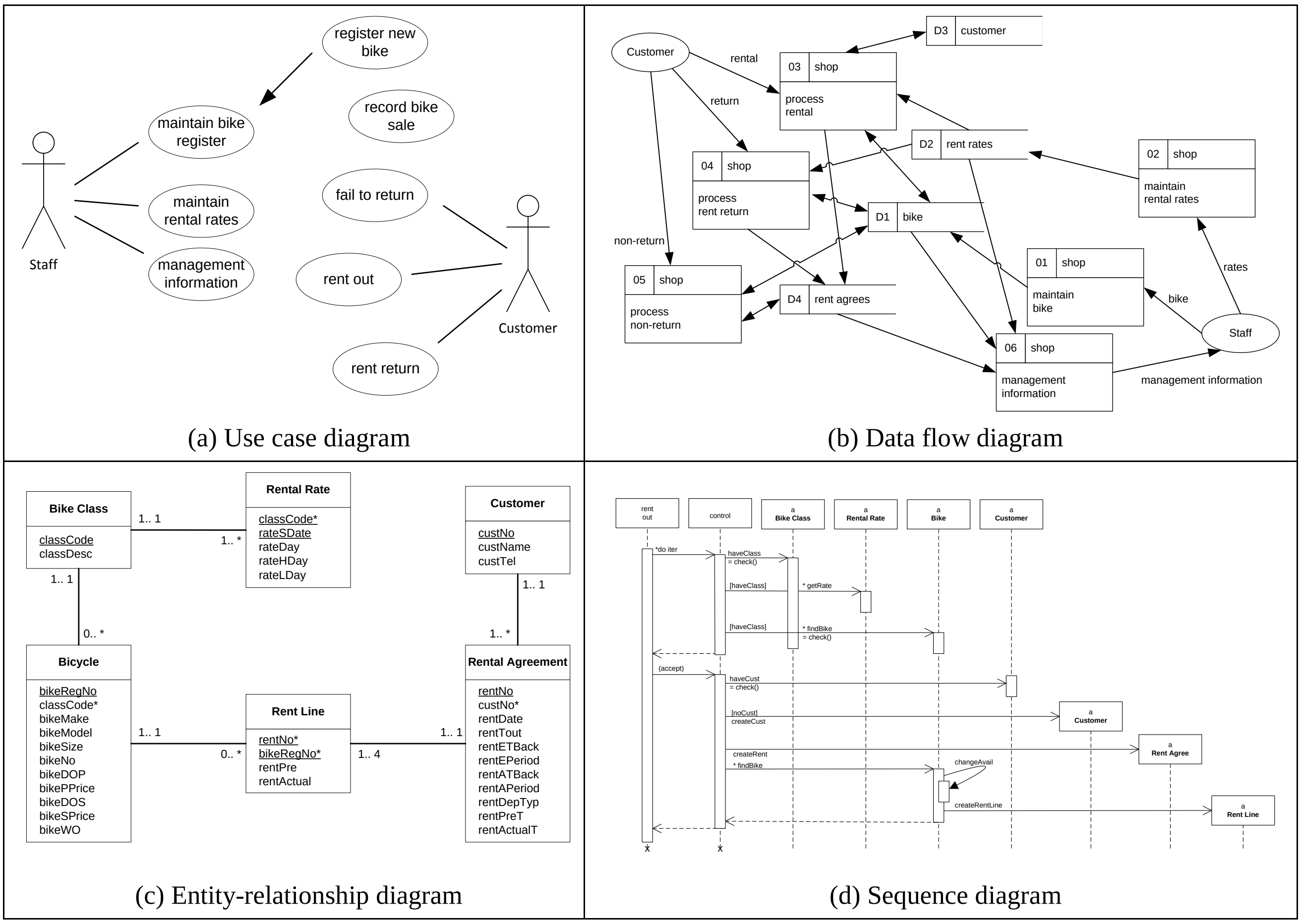



Figure 2: Different conceptual models for the High Peak Bicycles case (Whiteley 2013, pp. 228-263)

The new theory contributes to prior literature by providing both an account and analysis procedure that allows for the re-examination of studies in which users were confronted with multiple models (such as those listed in Table 1, for example). We are not aware of any other theory that has contributed in this way before. Aside from being able to revisit past results and providing a post-hoc explanation to noted effects, the theory also offers precisely formulated expectations about three types of evaluation of the purposeful use of model combinations. Of course, the theory can be extended in several ways. One would be to extend the range of predictions beyond the three evaluations. A notable promising direction would be to develop predictions about the *design* of model combinations rather than their *interpretation* – which was the focus of our theorizing. A second direction flows from a broader examination of the tasks and the associated goals for which models are used. We focused on the development of domain understanding because any subsequent model usage for different analysis and design tasks (say, software specification versus system configuration versus process re-design) is ultimately dependent on how well individuals can comprehend the modelled domain (Burton-Jones and Meso 2008). Still, similar to existing research on using conceptual models for *specific* tasks such as the development of database queries (Bowen, O'Farrell and Rohde 2009), it would be useful to see how model combinations could assist these and other problem-solving tasks. Finally, we see a promising research direction in the development of appropriate measurements for our theory. For example, since users evaluate and subsequently use grammars differently based on the perceived levels of ontological completeness and clarity of the grammars (Recker et al. 2011), it will be important to understand how perceived levels of completeness and clarity of a model or entire sets of models impact evaluations of the models and the behaviours of the users working with these models.

In conclusion, we believe we have formulated a new theory that offers a more comprehensive and ecologically valid perspective on conceptual modelling and provides a solid theoretical platform that can stimulate further research in this area. In our own work we will pursue empirical testing and refinement of our new theory and we hope that fellow scholars will join his endeavour.

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