Construction Innovation

Implementation of the LPS using an excel spreadsheet: a case study from the New Zealand construction industry

Fahimeh Zaeri, James Olabode Bamidele Rotimi, M. Reza Hosseini, Jeff Cox,

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Abstract

Purpose: This study investigated the implementation challenges of one of lean construction's recent tools, the Last Planner System (LPS), by exploring issues in the New Zealand construction sector to identify potential areas for improvement. To achieve this aim, the study formulated two objectives: 1) to present the challenges in LPS use; and 2) to explore solutions through using an Excel spreadsheet to facilitate LPS applications.

Design/methodology/approach: The study drew primarily upon a case study approach. A fieldwork study and document analysis of a New Zealand construction project were conducted with an extensive literature review undertaken on the LPS concept.

Findings: The findings revealed that, although an automated spreadsheet could be a simple and inexpensive option for using the LPS, data collection, storage and transfer into the spreadsheet could significantly influence the LPS outcomes' reliability. Most data utilisation challenges were found to occur around the three data sets included in the Weekly Work Plan (WWP). The study presented several automation solutions which had been applied to overcome data utilisation challenges.

Originality/value: Among the first of its kind in the construction industry, this study, with its first-hand account of an organisation which uses the lean paradigm, provides an in-depth insight into LPS tool implementation. The study extends the current body of knowledge through unearthing the challenges of LPS integration into construction activities and presenting efforts undertaken in a construction case project to overcome relevant issues. This adds value through enhancing the reliability of the LPS and, consequently, the effectiveness of its implementation in practical terms.

Keywords: Last Planner System (LPS), challenges, Percent Plan Complete (PPC), automation, spreadsheet

Paper category: Research paper

Introduction

Construction projects are becoming progressively larger and increasingly more complicated with a major concern being the need to improve project management practices to enhance productivity (Froese, 2010). Construction project managers therefore struggle with project productivity issues. These issues for the most part could be attributed to poor project management; thus, there is a dire need for novel project management practices (AlSehaimi *et al.*, 2014). Practical implementation of these practices on projects could help the construction industry to overcome challenges and eventually improve productivity.

One of the recent approaches, which evolved in response to the challenges faced by traditional project management techniques, is lean construction (Jørgensen and Emmitt, 2009). According to Bertelsen (2002), the major focus of lean construction is on understanding construction as a production and planning process, thus managing the workflow within the construction process. The most common lean construction technique is the Last Planner System (LPS) (AlSehaimi *et al.*, 2014) which was developed by construction industry practitioners for managing construction projects (Daniel *et al.*, 2015). The main focus of the LPS is on reducing the negative impacts of variability and increasing the predictability and reliability of workflow for production planning and control (Mossman, 2009; Daniel *et al.*, 2015). The LPS tool comprises a number of integrated components, namely: Master Plan; Phase Planning; Lookahead Planning; Weekly Planning or Weekly Work Plan (WWP); Percent Plan Complete (PPC); and Reasons for Non-Completion (Hamzeh *et al.*, 2008; AlSehaimi *et al.*, 2014). Analysis by Daniel *et al.* (2015) of the LPS studies illustrated that, among the LPS components, Measuring the PPC has received the highest level of attention. Likewise, Ballard (2000) stated that PPC measurement can support continuous improvement as it provides teams with the lessons learned through identifying the reasons for non-completion of tasks. The measurement of the PPC is treated as an important process as it shows plan reliability (Choo *et al.*, 1998), and reflects project productivity (Liu and Ballard, 2008) and the effectiveness of lean construction practices (Bertelsen, 2002). In essence, LPS utilisation has been an active field of research (Bertelsen, 2002; Alarcón *et al.*, 2005; Hamzeh, 2009) with PPC measurement being the primary focus. Nevertheless, the mechanism by which these tools work and the measures taken to improve projects that use them have remained elusive in the extant literature (Priven and Sacks, 2016).

The present study's literature review showed that the roles of database development and PPC measurement have been considered as two individual areas with significant influence on LPS efficiency. Despite this salience, studies that target the linking of these areas were conspicuously absent. To address this gap in the body of knowledge, the present study aimed to address the effects of data utilisation on the use of the LPS by formulating the following objectives:

- To present the challenges related to LPS use
- To explore solutions through using an Excel spreadsheet to facilitate LPS applications

This paper first reviews the LPS and its important component, the Percent Plan Complete (PPC). The paper then continues by presenting the research method employed in this research. As the research used a case study approach, at the end of the research method section, the case descriptions are presented to draw a clear picture of the circumstances in which the LPS was utilised. The final three sections of the paper discuss and present the research findings, responses to these findings and the conclusions.

Last Planner System (LPS)

Some key concepts—value, flow and pull—support project managers in their objective of improving productivity (Ballard and Howell, 2004). However, different conceptualisations of a project and its management bring different assumptions to project management techniques. For example, the traditional concept of a project defines a project as a delivery endeavour in conformance to contractors, but neglects waste minimisation and value maximisation goals, leading to the assumption that workflow is beyond the scope of project management (Ballard and Howell, 2004). Within this traditional concept, project management methods do not attempt to reduce variability in the workflow: consequently, the effects of variability on the budget and schedule are overlooked. Evidence in the literature has suggested that a wide range of issues in the construction industry stem from such traditional approaches (Spearman and Hopp, 1996; Vrijhoef and Koskela, 2000; Green *et al.*, 2005).

The lean paradigm therefore evolved to eliminate these issues by emphasising workflow reliability, maximisation of value for customers and minimisation of waste (Ballard and Howell, 1998; Jørgensen and Emmitt, 2009). As indicated in the literature, the use of lean construction has become a popular practice for improving construction projects' productivity (Alarcón *et al.*, 2000; Al-Sudairi, 2007).

Lean construction practices emphasise the use of the LPS as a management tool (Ballard and Howell, 1998; Gao and Low, 2014). The LPS is defined as a process that targets the maturing of tasks over time; a mechanism that enhances coordination among contractors, subcontractors and their crews; and a measure that assesses the stability of work plans (Priven and Sacks, 2016). As asserted by AlSehaimi *et al.* (2014, p. 52) "[t]he best known lean construction technique is the Last Planner System (LPS), which has been demonstrated as a very useful tool for the management of the construction process". According to Ballard and

Howell (1994), the LPS is a production management system which aims to improve workflow reliability. The LPS is designed to shield near-term work from the variability and uncertainty surrounding downstream works. This is achieved by collaborative planning among the LPS users (crews) in charge of productivity which facilitates the creation of detailed hand-off work plans for near-term work (Ballard and Howell, 1998). This tool has been implemented in different forms in various countries with its utilisation occurring at a significantly increasing pace (Fernandez-Solis *et al.*, 2012) due to the outcomes of the study by Ballard and Howell (1998). In a similar vein, Daniel *et al.* (2015) argued in their more recent study that the level of use of the LPS is increasing geographically and geometrically. In addition, Daniel *et al.* (2015) indicated that a wide range of studies have reported on the implementation of the LPS in projects in building construction; heavy civil engineering construction; and highway and infrastructure construction in different countries. A number of studies (Bertelsen, 2002; Alarcón *et al.*, 2005; Hamzeh, 2009) have addressed the significant applicability of the LPS to general perspectives such as management, scheduling and planning. Furthermore, the advantages of LPS implementation have been reported by scholars such as AlSehaimi *et al.* (2014); Fernandez-Solis *et al.* (2012); and Kim (2014), with Kim (2014) listing these advantages as follows:

1. Assisting the project team to overcome the inherent shortcomings arising from the contractual arrangement and delivery method
2. Identifying the main reasons for project variances
3. Achieving continuous improvement through PPC measurement
4. Successfully completing the project by team participation in weekly pull planning
5. Mitigating problems originating from the project structure.

Evidence from a wide range of perspectives including the information-sharing viewpoint has stated the advantages of the LPS (Fernandez-Solis *et al.*, 2012; Gao and Low, 2014). Alarcón *et al.* (2005) argued that LPS utilisation can provide project teams with increased levels of information related to the causes of broken promises and field interferences, and the percentages of occurrence of the common causes in the project. In addition, Ballard (2014), in answer to the question of why the LPS should be used, introduced some other key advantages. These include: 1) to improve labour productivity (of interest to those with a cost risk); 2) to better coordinate the work of different specialists (of interest to those with a schedule risk); and 3) to continuously improve the work (of interest to individuals who want to develop their capabilities and to companies that want to endure and thrive). Many scholars with interest in the advantages of LPS implementation have had a major focus on PPC measurement. The works of Ballard (2008); Liu and Ballard (2008); and Bertelsen (2002) are examples of studies that have evaluated the effectiveness of LPS utilisation through PPC measurement. In view of its central role in LPS implementation, the PPC is discussed in more detail in the next section.

Percent Plan Complete (PPC)

The Percent Plan Complete (PPC) is recorded daily and compiled weekly to monitor how the project is progressing (Kim, 2014). Ballard (1997) and Gao and Low (2014) explained that the PPC is calculated by dividing the number of completed tasks by the total number of tasks planned for each week. A high value for the PPC implies that the LPS is reliably forecasting the work; thus, the tasks are being completed according to the schedule (Gao and Low, 2014). Therefore, the PPC calculation calls for further information which has to be compiled from different sources. As Choo *et al.* (1998) highlighted, these sources could exist in electronic format in the company, possibly in the form of spreadsheets or word processor files, although they may not be available for use throughout the project. In this regard, Hammer (1990) emphasised the need to re-engineer the information process, terming this "capturing information once and at the source". Choo *et al.* (1998) applied Hammer's (1990) advice in the development of the lean application to generate the Weekly Work Plan (WWP) in the Work Plan database. In the same vein, Kim (2014) focused on the use of the related data. Kim (2014) added that data obtained from the database are useful as they can then be transformed into charts and graphs to analyse any trends occurring in the project's progress over the specific period. In this way, the initial data required for the analysis and improvement of the PPC measurement are provided (Ballard, 2000). As shown in the literature, PPC measurement calls for the availability of reliable data.

Research methods

The *constructivist* perspective was deemed the most applicable research paradigm for the present study. The reason is that a constructivist view relies on the participants' perceptions and feedback pertaining to their experiences in dealing with the topic of study (Creswell, 2014). The ontological stance associated with the constructivist research paradigm is commonly a *relativist* ontology which assumes that realities are reflected in the form of intangible mental constructions. These constructions are context-specific and shared among individuals in a setting (Guba and Lincoln, 1994). In terms of the epistemological view, a *subjectivist* view is valid for the constructivist paradigm in the present study. Subjectivist judgements present reliable sources of knowledge to uncover the issues faced in implementing novel methods and practices in construction organisational settings (Hosseini *et al.*, 2015). A recommended method for transferring this knowledge from a setting to the body of knowledge is by sharing experiences through conducting case studies (Guba and Lincoln, 1994).

In the context of lean and LPS practices, Daniel *et al.* (2015) reported that the use of the case study approach in LPS implementation is inevitable due to the practical nature of the implementation in construction operations. Consequently, the case study approach was adopted as the most applicable methodology for fulfilling the objectives of the present study. The selection of the case study as the primary method was further justified given that projects using the LPS are typically complex: not only are they restricted to a certain time period and location, but they are also affected by a particular organisational and project culture. Accordingly, taking a holistic approach by conducting a case study rather than using a reducible approach becomes tenable (Verschuren, 2003).

The design process for case studies involves deciding whether the unit of analysis for the study will be a single case (e.g. a person or an organisation) or multiple cases. Yin (2013) suggested four main types of case study design with selection to be on the basis of particular sets of conditions. As suggested by Yin (2013), single case design is in line with a holistic approach. Hence, in following Yin's (2013) case study definition, the substance of the case study in the present study embodied the exploration of a single project to shed light on how the LPS was implemented, what the results were and how the challenges faced were addressed.

Case selection

Following a systematic procedure to select the case to be studied in case study research plays a pivotal role in terms of the richness and the level of generalizability of the findings. According to Flyvbjerg (2006), selecting an "extreme case" might be an approach well suited to case study inquiries. Extreme cases for research could be identified as those that are "especially problematic" in a certain area.

Discussions with construction managers and academics while attending construction meetings in Auckland brought to light the point that LPS utilisation was quite new to the New Zealand (NZ) construction sector. Therefore, a very limited number of cases was available to provide the present study with an exploratory opportunity.

The case to be studied was selected from among construction organisations based in Auckland, NZ, while taking into consideration the following potential features:

- The construction organisation is interested in the implementation of lean techniques.
- The construction organisation is able to invest in training its employees in this context.
- The construction organisation is looking for opportunities to improve productivity.
- The construction organisation is keen to gain more project management advantages through automation and innovation (in line with the objective formulated by Building a Better New Zealand (BBNZ, 2011).

Considering the complexity of the project and the sheer number of team members and organisations involved, the selected case was deemed to be an extreme case. Another rationale for selecting this case study came from the *revelatory* standpoint, a term used by Yin (2013). *Revelatory* refers to cases which are rare and unique among their kind, therefore providing a golden opportunity for investigation by researchers with such an opportunity not commonly available (Yin, 2013).

The validity of generalisations drawn from a single case study is prone to criticism (Yin, 2013). However, as maintained by Flyvbjerg (2006, p. 225), "… it is incorrect to conclude that one cannot generalise from a single case. It depends on the case one is speaking of and how it is chosen". Single case studies have been extensively deployed for the exploration of new technology within the construction literature.

Data collection

The main data collection technique was designed to be conducted as fieldwork research involving field note taking and document analysis. Major parts of the data collection were undertaken through the analysis of documents obtained either from Orbit (the internal network used for storing the project's documents, such as operation instructions, meeting minutes, staff announcements, etc.) or from direct participation in site activities. Document analysis is a way of collecting data by reviewing existing documents: this can be used to collect background information, such as the history and operations of the studied organisation. Documents include reports, program logs, productivity ratings, meeting minutes and newsletters in electronic or hard copy format. Bowen (2009) identified document analysis as an efficient and cost-effective method as it does not depend on the availability or participation of certain groups of people. Insufficient details, low reliability and biased selectivity are identified limitations of this method (Bowen, 2009).

In the studied case, the organisation put a great deal of effort into starting its lean journey through four operations teams. No uniform method was used for collecting and recording the requisite data for their practices. In other words, each group built its own report template, with one of the groups recording manually in a notebook/diary. Different approaches in LPS practice were applied by different groups, such as weekly report presentation on a whiteboard, using simple tables or simply by verbally communicating at the weekly meeting. The users followed up with weekly LPS meetings to share experiences of LPS applications, updating the planning team and management with the progress percentage completion rate. Non-recorded information was a barricade to future access for further analysis. However, the authors collected all extant documents received through meetings or email, as well as carrying out note taking. Through this process, the present research compiled detailed information on the challenges faced in the utilisation of different LPS elements, and undertook analysis of the LPS data to identify constraints and reasons for non-completion of tasks.

Description of the studied case

The studied case is one of the largest and most important infrastructure developments ever to take place in New Zealand. The project is designed for the New Zealand Transport Agency (NZTA) by an alliance which includes companies from NZ and overseas with expertise in infrastructure. The roading project associated with one of the locations (West Auckland) included in the NZTA project was selected for the purpose of this research. It was thought that the project could offer a good chance of conducting this research and achieving its objectives as the project manager and planning team (Site Leadership Team [SLT]) had just decided to start using the LPS as a lean tool.

In line with the NZ construction industry's major concerns as reflected in the report issued by BBNZ (2011), the SLT developed the mission and vision of the implementation of the LPS to highlight the key advantages they sought to achieve in this way. According to the documents in Orbit, the main objectives of lean and LPS implementation were defined as listed in the items in Table 1.

<<Please insert Table1 here>>

To achieve the objectives in Table 1, the principal project manager attended the LPS training course organised through a private institution in NZ in early 2013. Yet, deployment of LPS started approximately a year after the beginning of the project. That is, the principal project manager immediately started the journey by sharing the knowledge gained with small groups (including team leaders [each subcontractor selected one person as a representative to be in charge of the LPS practice in this project, i.e. the Last Planner person] and the project's project managers [engineering manager, field manager and detailed planning manager]). These small groups gradually expanded into four teams. The LPS practice was conducted internally (among these groups) with a focus on time management. The users did not find the LPS to be a convenient tool in the early stages of implementation. They started utilising the LPS in different ways according to what they thought best suited their time and the crews' level of skills. In conducting this fieldwork study (which started in late 2013), it has been found that the management team tried to facilitate LPS implementation through developing an Excel spreadsheet database. The management team believed that this solution would be an inexpensive and valuable option which could enable the users to record and analyse data in a consistent and unified way.

In the first attempt, the original spreadsheet template, received by the principal project manager at the training course, was modified to incorporate the project's specific needs (see Figure 1). In this development journey, some of the case organisation's site teams with a good background knowledge in both construction and spreadsheet development were engaged.

<<Please insert Figure 1 here>>

As can be seen in Figure 1, many data points (such as data points 1, 2, 3, 4, 5 and 10) should be transferred from Master Plan to Lookahead Planning or transferred from another database. Alternatively, when the process was ongoing, data points (such as data points 6, 7, 9 and 11) could be inserted on the basis of regular site visits (usually from the daily/nightly report which should be recorded by one team member and then passed to the Last Planner person). In other words, data should be transferred from other sources to this template (called the LPS database in this paper). Based on the information collected from different crews, the Last Planner person should enter another data point (data point 8) into the LPS database. The score column has been designed for PPC measurement. Therefore, the users should score the completion of each task using 0 or 1, with a fully completed task scored as 1, or else scored as 0 to illustrate some barriers to task completion. In the case of a 0 score, the users should fill out the corresponding cell in the Reasons for Non-Completion column (shown in the LPS database as 'reason for score').

Findings of the study

One of the authors regularly participated in the case study project from December 2013 to May 2014, with this followed by attending weekly on-site meetings that were held in parallel with finalising the study's findings (December 2015). This led the present study to identify the issues in the form of the main challenges to LPS implementation in light of the studied case's objectives (see Table 1). The LPS implementation challenges that faced the users in relation to the use of the LPS database and that affected the project in terms of the use of LPS output to fulfil the defined objectives (see Table 1) are discussed below.

Initial challenges and solutions

In the early stages, no database was available where the users could record and store the project's data. As discussed above, several users recorded information in notebooks or diaries, or wrote it on the whiteboard to be addressed in their weekly meetings. In line with the objectives of LPS implementation in the studied case, as presented in Table 1, data needed to be analysed to assist in updating the Master Schedule and in measuring the productivity rate according to the information reported by different teams. Hence, the users (mainly the Last Planner personnel) experienced difficulty when trying to update, track and transfer information. Consequently, the Week Score Plan could not be accurately completed due to the lack of information. Moreover, the organisation was supposed to be identifying the most common constraints and was breaking promises in the reasons it had given for developing a more accurate schedule, such as avoiding facing the same problem in future steps. The deployment of the new method of construction, as mentioned earlier, added difficulties in terms of forecasting and accounting for typical constraints in the planning of such an operation. As a result, updating the plan; developing a more accurate schedule for a week, or five weeks, looking ahead; analysing the LPS information for the purposes of a case study which lacked a uniform approach; and using the LPS database all made LPS practice more challenging.

After providing the users with the same Excel spreadsheet, as presented in Figure 1, and then following up this fieldwork study, it was revealed that the problem related to the data was not limited to the database. The way of recording and presenting the constraints and reasons for non-completion of tasks using different terminologies was found to be another major issue in the studied case. These issues acted as barriers to further analysis on measuring the impacts of adverse factors on project progress and the PPC measurement. To resolve such issues, the Excel spreadsheet was revised again with two spreadsheets developed to facilitate the use of the LPS and to enhance the reliability of LPS data. The utilisation of these spreadsheets as described below, was examined by only one subcontractor company that was involved in several operational areas such as Abutments, Gantry, Demo, etc. (as shown in Figure 4). These spreadsheets were:

1. a spreadsheet (see Figure 2) which allowed the users to record the required information, for example, a template that could facilitate the transfer of the required data to the Week Score Plan as well as supporting the case study project to achieve objectives 1, 2, 3 and 5, as presented in Table 1
2. the specific spreadsheet templates for the Week Score Plan which could, firstly, facilitate the use of the LPS and, secondly, enhance the reliability of the LPS outcomes. Thus, the studied case was deemed to be supported in achieving objectives 4, 6 and 7, as presented in Table 1.

Furthermore, by analysing the Week Score Plans submitted over the specific period of one author's participation (almost five months) in addition to notes taken in the weekly LPS meetings, the study was able to identify the major challenges that the Week Score Plans presented to the users. Major issues were found to have arisen from the completion of data points 6, 8 and 9 (Figure 1). Therefore, particular attention was paid to these data points as potential areas for the improvement of LPS implementation.

For example, wrong digits recorded in data point 8 resulted in the incorrect calculation of PPC rates. As shown in Figure 1, according to the digits entered (regardless of '2' which has been entered by mistake), the yellow cell at the end of the column should be 67% instead of 32%. The reason is that the total number of tasks in progress was 9, and sum of the scores was 6. Therefore, PPC = 67% (calculated by 6/9). It was necessary to apply modifications to increase the level of restrictions on data entry by the users and, consequently, to address the challenges. To this end, an automated Excel spreadsheet was developed and applied as described in the following section.

<<Please insert Figure 2 here>>

Automating the Excel spreadsheet

Subsequent to identifying the challenges, the present research continued by exploring the automated solutions that had been utilised by the case organisation. To mitigate such issues, a spreadsheet was developed which not only minimised the effort of the users in entering data, but also avoided manipulation and inflation of errors. This process started by developing the LPS database for one of the groups early in 2014. Three months later, when the database was found to be beneficial, the remainder of the LPS practitioners were provided with the same database to record and store their data in such a way that it could easily be accessed for further utilisation (in terms of transfer and analysis).

The LPS database was designed to support the studied case with the aforementioned objectives (presented in Table 1). For example, the analysis of information included in parts A1 and A2 (see Figure 2) can assist a project in estimating the duration and effective operation hours. In addition, information collected from parts B1 and B2 could be transferred to the LPS Week Score Plan as well as updating the Master Schedule and Lookahead Planning.

Another spreadsheet, Week Score Plan, was also revised, using Visual Basic for Applications (VBA), to respond to the discussed challenges. More details are presented in the next section.

This automated version of the spreadsheet was mainly developed to address the following challenges:

1. non-recorded information which appeared as blank cells in the spreadsheet
2. incorrect data which could be from typing errors or from inserting irrelevant information.

Developing a response to challenge 1

The first category was concerned with challenges related to missed data, in other words, when compulsory data were not entered by the users in the spreadsheet in the right place. For example, cells corresponding to those tasks which had been scored 0 might have been left blank or have been filled out with inappropriate information. Moreover, the users could explain the reasons in different ways (using a variety of wording). Therefore, to resolve this challenge, the following ideas were applied:

1. Creating a drop-down box menu (see Figure 3[a]) which included the list of different types of constraints/reasons for non-completion of tasks to help the users to select the reasons or constraints from the list. In other words, the list provided them with some ideas about what should be recorded in terms of reasons/constraints. The menu also facilitated the analysis of the constraints as the users used the same wording. In this way, typographical errors could not influence the analysis process. Therefore, those working on the studied case project were able to classify different reasons/constraints; identify the frequencies of the occurrences of different types of constraints/reasons; and later arrive at more accurate decisions to prevent or mitigate the occurrence of those factors.
2. Creating mandatory cells to correspond to non-completed tasks in which the users have to select the type of reasons for non-completion of tasks. Otherwise, a message would pop up to remind the users that the mandatory cell needed to be filled out. In

addition, the commands applied would prevent saving and closing the file (Figure 3[b]).

Developing a response to challenge 2

As explained earlier, this type of challenge arose from inserting incorrect or irrelevant data. Therefore, to overcome such issues, the spreadsheet was automated which restricted data entry by the user to the options listed in the drop-down box menu (see Figure 3[c]). In response to this challenge, it was found that some of the cells needed to be formulated to measure the PPC and the average score (Figure 3[d]). Through this action, user faults would be minimised and, consequently, the studied case project would achieve more reliable LPS outputs.

<<Please insert Figure 3 here>>

Discussion of the findings

In exploring the development of the spreadsheet LPS database in the studied case through such a simple inexpensive option, the present study opened up a new view of the challenges in LPS implementation which have arisen from data recording and utilisation.

The findings revealed two major issues: 1) non-recorded information which appeared as blank cells in the spreadsheet; and 2) incorrect data which could be from typing errors or from inserting irrelevant information, with these issues leading to inaccurate calculation of PPC measurements in the case organisation. These new and specific types of challenges should be taken into account by LPS users, especially by those using a spreadsheet database for LPS utilisation. In addition to identifying these challenges, the present study has highlighted that the integration of an automated spreadsheet could be advantageous in making LPS implementation more efficient. For example, the solutions applied which restricted data entry and/or required users to select options for describing causes from a drop-down box menu helped to enhance the reliability of data, to facilitate LPS implementation and to expand the dimensions where the LPS could be practised. As illustrated in Figure 4, the automated version of the LPS spreadsheet gave the studied case a chance to track the PPC measurement and to analyse the constraints. As illustrated in Figure 4, the automated version of the LPS spreadsheet gave the studied case a chance to access reliable data as well as the capability to automatically track the PPC measurement by producing a graphical report on the trends of PPC.

<<Please insert Figure 4 here>>

With regard to LPS challenges as addressed by previous researchers (Alarcón *et al.*, 2005; Hamzeh, 2009), the present study has identified the challenges in a practical and detailed context. To be specific, the study has provided a detailed insight and has raised the awareness of LPS users about the level of sensitivity of the LPS and the PPC to data recording and to inferences drawn from these data. Furthermore, the present study's findings have extended the database-oriented views of Ballard (2000) and Kim (2014) by addressing the link between the database and further analysis, mainly in relation to the PPC measurement. According to the findings presented in this paper, these two areas significantly influence each other through this link which is exposed due to the aforementioned challenges. Moreover, utilising the recorded data for the analysis process and/or transforming them into charts and graphs (Kim,

2014) are dependent not only on the accuracy of the data being recorded, but also on the accuracy of the process of transferring and utilising data from the database.

Conclusion

The present study has contributed to the body of knowledge through raising awareness of the extent to which data utilisation practices impact on LPS implementation, with this having been identified as an area in need of particular attention. The solutions presented here could be translated into guidelines and instructions for construction practitioners. For example, these findings could later be transferred into the LPS/WWP as well as being used to help meet the need to develop more efficient LPS/WWP templates.

The present study's findings have illustrated that using a simple inexpensive automated Excel spreadsheet can create a smoother process for analysing the occurrences of constraints and causes for non-completion of tasks in implementing the LPS in a construction project. The results can assist similar projects and lead to smoother and more efficient use of resources in LPS implementation. In terms of its contribution to industry, this study can strengthen the confidence with which construction practitioners apply the LPS to improve production flows, through the adoption of simple inexpensive Excel spreadsheets in LPS utilisation.

Despite the present study's contributions, the findings should be considered in light of the limitations that have affected the study process. This research was limited to a study of one of the largest construction projects in the NZ construction industry. As a result, the findings need to be seen as context-specific; hence, application of the findings in settings different from those of the studied case should be treated with caution. However, the present study's findings could be regarded as a relevant preliminary step in the development of an automated spreadsheet for LPS implementation. Further studies could focus on developing a fully-automated version of the LPS/WWP in order to present its advantages in various aspects.

These aspects could include: tracking productivity; updating the Master Schedule; analysing the causes for non-completion of tasks; preparing more accurate reports for sharing lessons learned; and, consequently, improving project productivity. In addition, other valuable areas of research would be investigating what factors affect the achievement of the primary objectives of adopting the LPS on construction projects, and presenting rigorous evaluations of the success or failure of projects in fulfilling these objectives. Exploring the areas for improving the planning practices particularly identifying the measures to enhance the details of planning is another area to be considered for future research on the topic.

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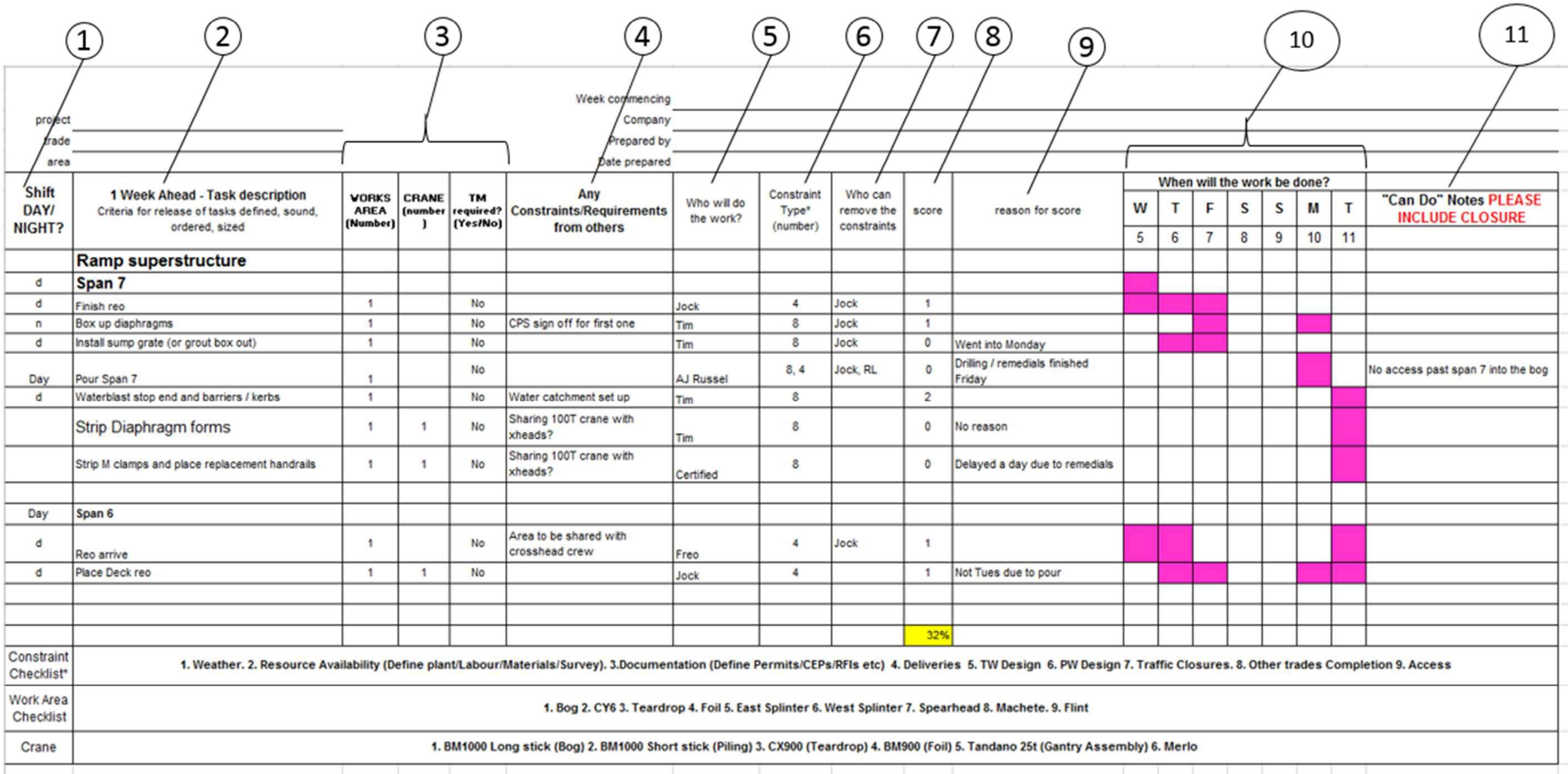

Shift DAY/ NIGHT?	1 Week Ahead - Task description Criteria for release of tasks defined, sound, ordered, sized	VORKS AREA (Number)	CRANE (number)	TM required? (Yes/No)	Any Constraints/Requirements from others	Who will do the work?	Constraint Type* (number)	Who can remove the constraints	score	reason for score	When will the work be done? W 5	T 6	F 7	S 8	S 9	M 10	T 11	"Can Do" Notes PLEASE INCLUDE CLOSURE
	Ramp superstructure																	
d	Span 7																	
d	Finish reo	1		No		Jock	4	Jock	1									
n	Box up diaphragms	1		No	CPS sign off for first one	Tim	8	Jock	1									
d	Install sump grate (or grout box out)	1		No		Tim	8	Jock	0	Went into Monday								
Day	Pour Span 7	1		No		AJ Russel	8, 4	Jock, RL	0	Drilling / remedials finished Friday								No access past span 7 into the bog
d	Waterblast stop end and barriers / kerbs	1		No	Water catchment set up	Tim	8		2									
	Strip Diaphragm forms	1	1	No	Sharing 100T crane with xheads?	Tim	8		0	No reason								
	Strip M clamps and place replacement handrails	1	1	No	Sharing 100T crane with xheads?	Certified	8		0	Delayed a day due to remedials								
Day	Span 6																	
d	Reo arrive	1		No	Area to be shared with crosshead crew	Freo	4	Jock	1									
d	Place Deck reo	1	1	No		Jock	4		1	Not Tues due to pour								
									32%									
Constraint Checklist*	1. Weather. 2. Resource Availability (Define plant/Labour/Materials/Survey). 3.Documentation (Define Permits/CEPs/RFIs etc) 4. Deliveries 5. TW Design 6. PW Design 7. Traffic Closures. 8. Other trades Completion 9. Access																	
Work Area Checklist	1. Bog 2. CY6 3. Teardrop 4. Foil 5. East Splinter 6. West Splinter 7. Spearhead 8. Machete. 9. Flint																	
Crane	1. BM1000 Long stick (Bog) 2. BM1000 Short stick (Piling) 3. CX900 (Teardrop) 4. BM900 (Foil) 5. Tandano 25t (Gantry Assembly) 6. Merlo																	

Figure 1. Preliminary version of spreadsheet template used for LPS implementation

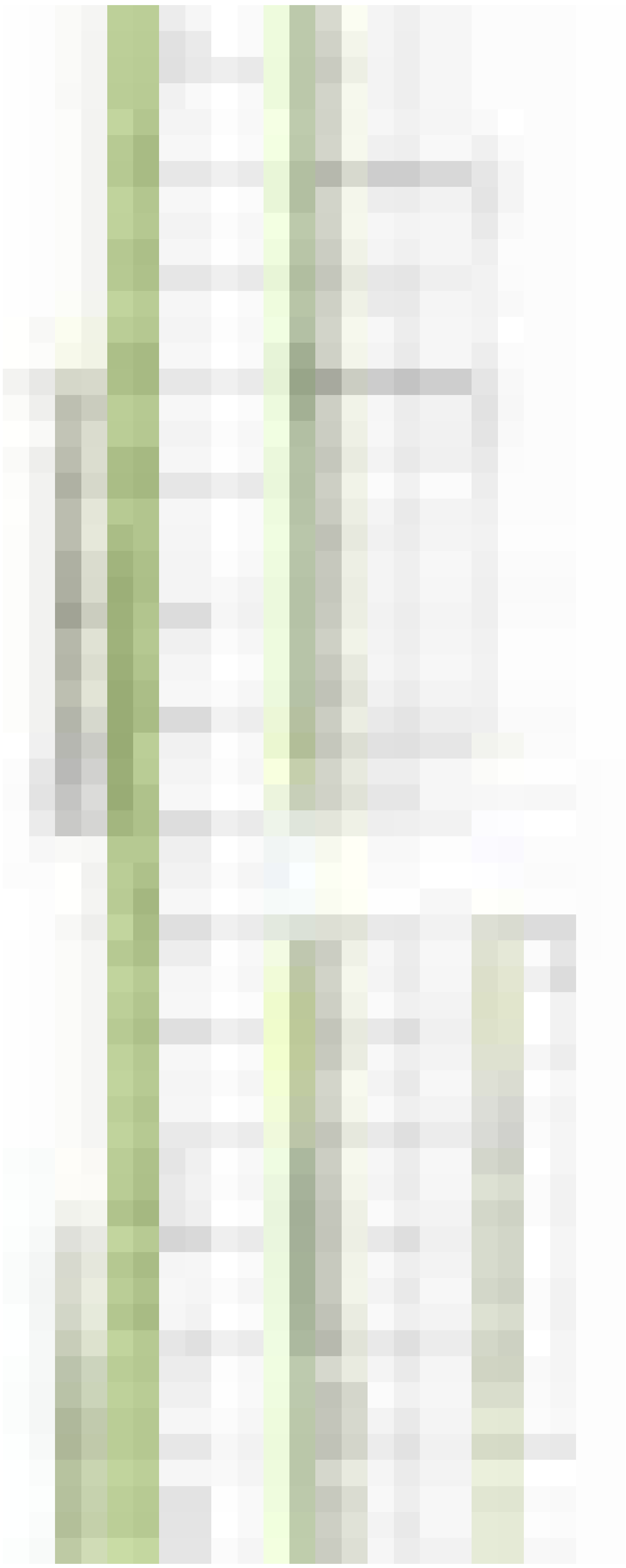

Figure 2. Database developed to record required data

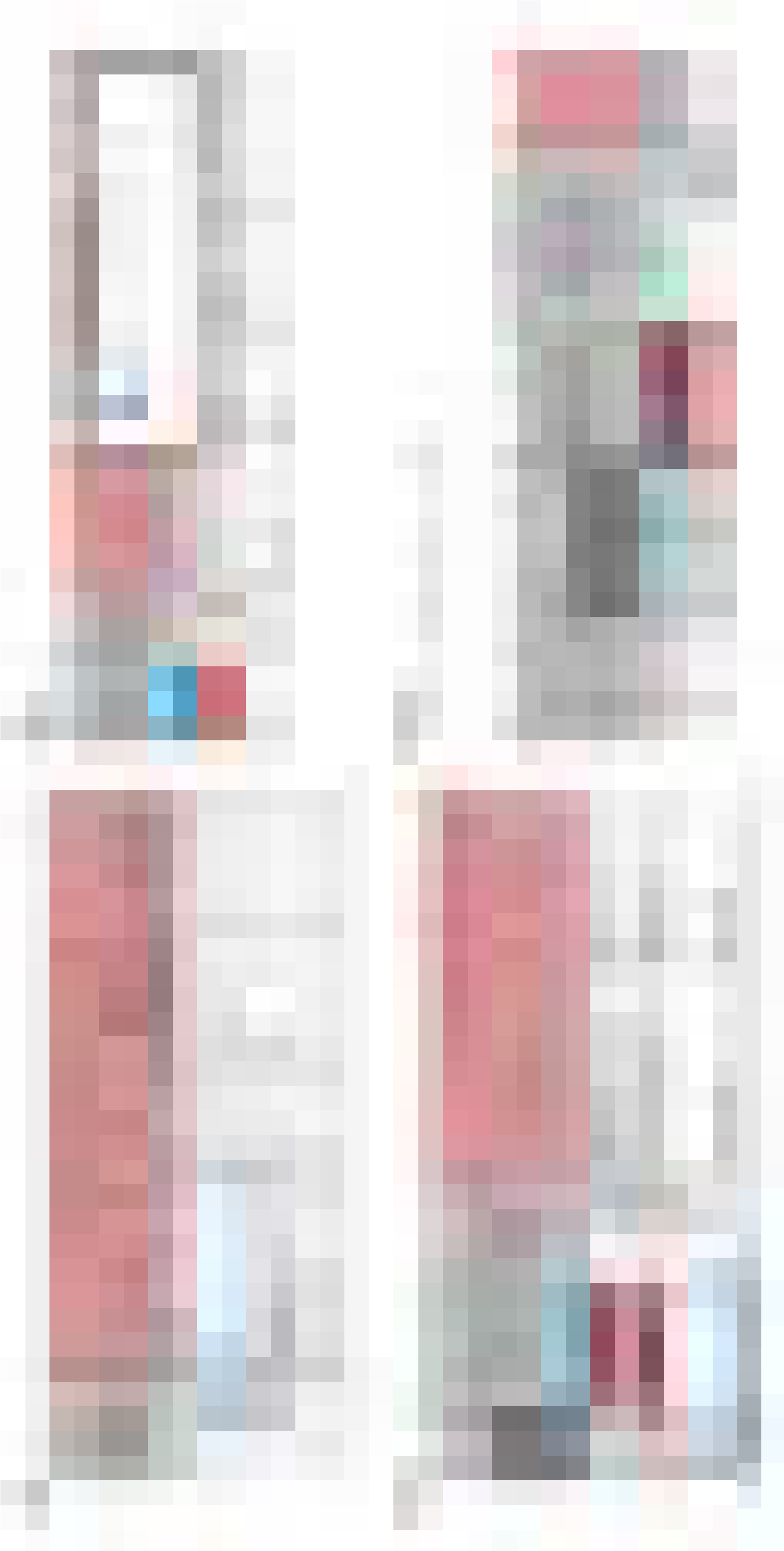

Figure 3. Automated solutions to challenges in LPS implementation

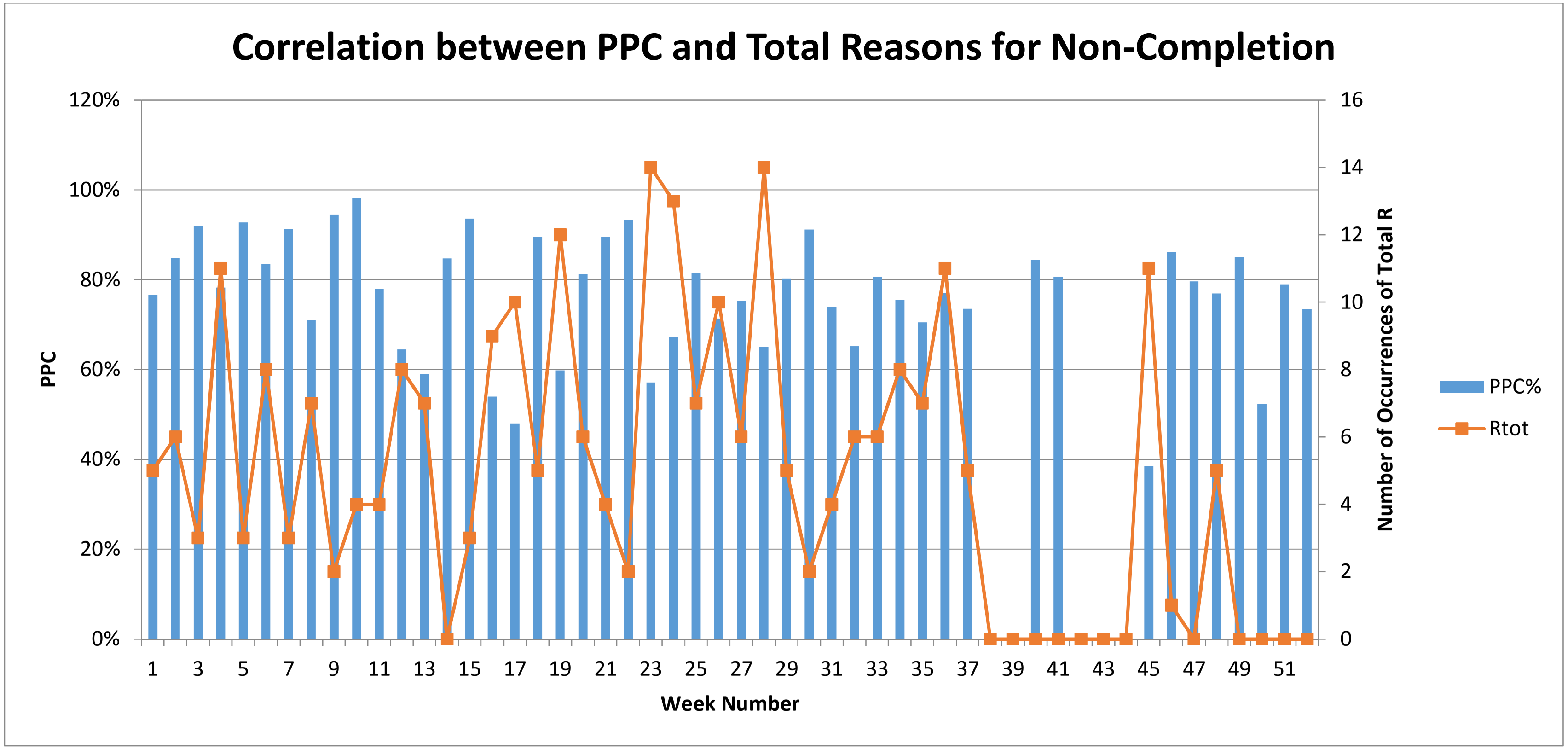

Figure 4. Advantages of automating LPS spreadsheet in root cause analysis process

Notes: R = Reasons for non-completion; Rtot = total number of reasons which cause delays or breakdown each week

Table 1. Main objectives for lean and LPS implementation in the studied case

Objective	Description
Objective 1	Estimating the average duration of the operation
Objective 2	Presenting the trend of operating hours
Objective 3	Measuring effective operating hours
Objective 4	Controlling the factors which cause breaks or delays
Objective 5	Updating the Master Plan (MSP) format
Objective 6	Identifying the constraints, and determining the impacts of their frequency on the project schedule and budget
Objective 7	Reducing the operating hours while increasing the productivity rate