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Understanding the Planner's Role in Lookahead Production Planning

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ABSTRACT

Capacity planning is a crucial step in production planning where resource capacity should be properly assigned to match the tasks' load shown on the schedule. Variability permeates both sides of the load and capacity equation and complicates the planner's role in striking a proper balance between the two. The purpose of this research is to study the relationship between the type of capacity planning and project's time and cost performance. A simulation model is developed to test several projects' profiles against different planning techniques adopted by the planner to decide on weekly capacities. Cost and time metrics are developed to track the project's performance throughout its entire duration. Also a measure of quality is introduced to investigate the quality of the capacity planning for each planning type. Results show that the capacity planning method affects project's cost and duration. Nonetheless, the quality of capacity planning is sensitive to the planning type as well as project's characteristics. Interestingly, informed planners who are aware of their project's characteristic were able to strike the best balance between weekly load and capacity. Thus, they were able to avoid extra incurred costs wasted on idle resources without significantly affecting project's duration.

KEY WORDS

Capacity planning, resource management, simulation, construction planning, lookahead planning.

1 INTRODUCTION

Planning is crucial in directing a project to meet its objectives of time, cost, quality, and safety (Laufer et al. 1993). The role of planning is critical at early project phases where proper allocation of time and resources to planning efforts increases the probability of success. Furthermore, much of the hidden risk encountered during the execution phase can be greatly reduced (Aziz & Hafez, 2013). Moreover, planning during project execution is also very important, especially that new circumstances may appear on site that can alter the pre-set plan, calling for new actions. However, one major challenge that is often encountered during project execution is capacity planning which involves a judicious allocation of a certain resource capacity to match the task load expected from the schedule. An understanding of the relationship between load and capacity, the included variability, and the planner's role is required to strike a proper balance between the two.

Investment in planning at early project phases is a determinant of project success. At this stage, the project's scope is defined, requirements are delineated, and the technical specifications are developed (Dvir, Raz, & Shenhar, 2003). However, not all projects apply proper early project planning. In fact, only one third of projects have made use of developed early planning phases (Hamilton & Gibson Jr., 1996). Moreover, not enough time is allocated to properly plan average projects despite the research results showing that effort put into the planning phase has the strongest relationship to adding value to customers, stakeholders and the company (Serrador & Turner, 2015).

Different project stages require different levels of planning efforts. Planning is done from a long-term perspective first, and then from a short-term perspective. The long-term planning starts by setting the major milestones of the project, and proceeds by breaking these milestones down into defined phases. Later on, the short-term planning starts by developing the 6-week lookahead plans, and breaking them down to weekly work plans (WWP) ready for site execution. Therefore, planning is done in greater detail the closer we get to start the activity

(Hamzeh & Langerud, 2011). Similarly, Junnonen and Seppanen state that a task is planned in such way so that when executed and completed, it will fulfill the objectives and requirements it sought out to fulfill. Note that different aspects of the execution of the task are planned including its relation to schedule, its quality, and its readiness as far as prerequisites are well-defined and met. Additionally, an important step in task planning is the analysis of the potential problems that might arise; a what-if analysis (Junnonen & Seppanen, 2004). After all, the problems that might arise are largely due to the existence of unforeseen circumstances and the presence of variability.

Variability is a fact of life that we cannot change, and it can be found everywhere, and the field of construction is no exception. Ben-Haim and Laufer distinguish between two types of uncertainty. It can either be structured, which is the usual year to year variation of the weather in a certain date for example, or unstructured which is "a substantial information-gap between what we do know and what we need to know to perform optimally" (Ben-Haim & Laufer, 1998). Furthermore, variability and uncertainty negatively affect many aspects of project performance including sub-optimal production, increased cycle times and increased costs (Gupta, Gonzalez, & Miller 2012). When it comes to construction projects, variability can be detected in factors such as the production rate, the productivity of labor, and the schedules of construction (Gonzalez, Alacron, & Molenaar, 2009). Uncertainty and/or variability have been acknowledged as reasons for poor construction project performance (Ballard & Howell, 1998). Tommelein at al. created the Parade Game to illustrate how variability impacts performance and production. They concluded that variability and unreliable workflow cause a decrease in throughput, a delayed completion date for the project, and an increase in waste; where some production phases do not use their full output capacity because they starve for resources (Tommelein, Riley, & Howell, 1998).

Lindhard and Wandahl suggested two methods to reduce/absorb variability. The first method is to increase flexibility by adding time slack to critical activities which helps absorb variability in productivity and improve the ability to react to unforeseen happenings. The second approach suggested is to use buffers to attain flexibility. Buffering is a well-known go-to practice in project planning. Buffers, whether inventory buffers, capacity buffers, or time buffers, are seen as tools used to absorb and/or reduce the effects of problems and issues by way of accommodating uncertainty and variability (Sakamoto, Horman, & Thomas, 2002).

But how much buffering is enough? According to Gupta et al., the problem between productivity and the size of the buffer seems to be a "balance problem". The smaller the buffer size, the lower the productivity and the higher the sensitivity of production towards variability. However, there is a certain buffer size beyond which an increase in the buffer size will have "no significant advantage in mitigating productivity loss due to variability". Thus, even if buffers may not significantly improve productivity, they do provide a level of productivity protection against variability (Gupta, Gonzalez, & Miller 2012). Furthermore, Park and Pena-Mora concluded that an adequately pooled, resized, relocated, and re-characterized buffer can aid in shortening project's duration short of radically increasing costs (Park & Pena-Mora, 2004). Lee at al. determined that by applying a reliability and stability buffering approach, planners can reduce the amount of hidden errors and latent changes; identify the predecessors' errors and changes in concurrent design and construction; prevent their ripple effect on the succeeding activities; and increase the quality of the coordination process (Lee, Pena-Mora, & Park, 2006).

Till now, nobody has completely understood or has been able to explain the dynamics of variability in its entirety. Had someone been able to exactly predict weekly variability and account for it, production planning would not face the problem of matching weekly loads and capacity. Accordingly, striking the exact size of resources for a certain activity is not possible, and therefore, we fall in the problem of matching weekly load and capacity which is not an easy task to achieve. In this context, Ballard defines load as the quantity of work needed to be done in a specific time allotted by planners, and capacity is the quantity of work a crew can complete given their tools, methods of work, and conditions on-site (Ballard, 2000). When load and capacity estimates are different from the actual measurements, the planning crew must either alter load to match capacity by postponing or fast-tracking work flow, alter capacity to meet load by changing the quantity of resources, or an amalgamation of both (Gonzalez V. , Alacron, Mundaca, & Jose, 2010). Therefore, the aim of production planning is to match load and capacity with maximum possible accuracy based on given circumstances (Ballard, Kim, Jang, & Liu, 2007).

Thus, production planners require information regarding workloads and resource capacity. Kim et al. came up with a workforce information (level of skill, history of accidents…) database to help solve the problem of matching load and capacity. The workforce database system helps the planner better estimate the capacity of a certain crew, and allows the planner to better size the needed crew for a defined work load (Kim et al. 2008). The database solves the problem of estimating the capacity of a certain crew; however, it cannot help in predicating weekly loads. The load in weekly work plans is not fixed nor stable, and therefore the choice of crew size and the capacity in a certain week is decided by the planner on site. Thus, the database system helps ameliorate the sizing of crews but cannot alone solve the problem of matching load and capacity due to the continuous variability on site.

Therefore, previous efforts focused on the scope of planning required at each phase of the project, the variability encountered in projects and its effects on production, the buffering solutions to absorb variability, and the labor information databases that help planners better estimate the capacity of a certain crew. However, all these studies ignore the role of the planner in deciding the capacity size needed to execute a weekly work plan, and give no insights about how these choices affect construction production in a changing environment. Note that the variability witnessed in projects is manifested in three different ways: the variability of expected load in the WWP, the variability of capacity choice decided by the planner, and the variability of the actual work ready for execution in the corresponding week.

In this regard, this paper aims to study the impact of the planning method adopted by the planner to match load and capacity when executing weekly work plans. While the lookahead plan provides the expected weekly work load resulting from the making ready process, the choice of capacity size is a planner's choice based on his experience and perception of project's performance. It is not a one to one correlation. Nonetheless, the variability rooted in the lookahead process necessitates the intervention of the planner to balance the production, keeping in mind the incurred capacity costs and the completion time of tasks. To correlate planner's choice in choosing weekly capacity to the performance of the project, this study defines two categories of planners, Informed and Un-Informed planners, along with nine project profiles having different stochastic characteristics. Informed planners are those who follow their project's metrics and use them to decide on their weekly capacity. Whereas, Un-Informed planners either follow a constant CAP approach throughout the entire project, or randomly select their weekly capacity. The study then investigates the planning method adopted by the planner against several project's circumstances, and the research question can be stated as follows:

How does capacity planning affects the execution of the lookahead plan and the performance of the project in a continuously changing environment?

The paper is organized as follows: section 2 highlights the research method and the corresponding experimental design. Section 3 presents the results of the simulation experiments and discusses the findings. Section 4 concludes, and appendix A presents a summary of the abbreviations and terminology used throughout the paper.

2 RESEARCH METHOD

Simulation is selected in this study over other experimental methods for several reasons. First, simulation helps modeling the lookahead plan under several project's stochastic conditions. Second, simulation gives researchers higher control on parameters' values and enables them to test different experimental combinations one at a time. Third, it is impossible to investigate all different profiles on a real project, where uncontrolled consequences may affect project's progress. Accordingly, a discrete event simulation model is developed to mimic the practical implementation of the lookahead plan by including several types of capacity planning methods. Note that the model used in this study is already developed in a different published paper. For further information, refer to Hamzeh et al. (2015). In this study, researchers use the same model to investigate another aspect encountered while implementing the lookahead planning method: Capacity Planning. Section 2.1 highlights the corresponding experimental design and the technical aspects of the study.

Simulation is defined as "the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/ or evaluating various strategies for the operation of the system" (Shannon 1998). In construction, simulation can be understood as the "science of developing and experimenting with computer-based representations of construction systems to understand their underlying behavior "(AbouRizk 2010). Modeling is aimed at solving problems that plague systems in the real world. While it is often very difficult to experiment with real system where introducing changes to the system may be too expensive, dangerous, or just impossible, simulation offers a solution by building a model of the system and representing it in a modeling language (Axelrod 2006, Borshchev 2013).

In this study, discrete event simulation is employed to model the lookahead planning process on a construction project. When modeling the system in discrete event simulation, the resulting simulation model is a surrogate model of the real system that considers only the important events in the system's lifetime. To build the model, some abstraction is required where some details that are considered irrelevant to the problem under study are taken out and details that are important are kept in. Therefore, the simulation model built is always less complex than the original system. Building and running the model results in a better understanding of the structure and behavior of the original system by testing how the system behaves under various conditions, comparing different scenarios, testing hypotheses, and looking for optimal solutions (Axelrod 2006, Borshchev 2013, Dooley, 2002, Martinez 2010).

To verify the model and answer the question "Did we build the model right?" (Law 2014), the computer model underwent several steps as advocated by Bennett, et al. (2013): 1) assess the model's aim and scope, 2) check the project input, 3) analyze visual performance, 4) select basic performance criteria (Project Duration, CRRIs, and CPQ), and 5) introduce refinements to ensure that the simulation model delivers what the designers intended.

To test the model validity and answer the question "Did we build the right model?" (Law 2014), the following validation techniques, stipulated by Sargent (2011), were performed: 1) animation tests, where the model's operational behavior was analyzed graphically as the model moves through the project week by week plotting output parameters CRRIs, CPQs, and duration while visually checking for Done, Not Done tasks, and pebbles going back to join the queue; 2) face validation, where academics and practitioners who are knowledgeable about the real system were consulted to validate the logic of the model's concept and behavior as well as the rationality of the model's input and output; 3) operational graphics, where values for the number of Done vs. Not Done tasks, tasks returning to the lookahead schedule, CPQ and CRRV were monitored on week to week basis (advancing the model simulation time) to ensure that calculations of output values do match the number of tasks in each queue.

2.1 Experimental Design

The lookahead plan, presented in Figure 1, is simulated according to nine different project profiles. Each project profile corresponds to a combination of values assigned to the project performance parameters: R, RR, P, NR, NBR and N (refer to Appendix A for terminology). Table 1 highlights the nine scenarios and the corresponding parameters' values. Profile 1 is intended to be a base or reference case, whereas profiles 2 to 9 investigate the effects of changing the values of these parameters on project's duration and performance with respect to the base case. The variability of values assigned to the performance parameters is intended to represent the variability witnessed in the making ready process without significantly affecting the characteristics of each profile. Therefore, parameters' values are assigned to uniformly vary between -0.15 and +0.15 around their average values to create variability in the generated work load.

Planners are continuously engaged in the lookahead planning and the making ready process; however, their intervention throughout the process differs based on which relative week is being under focus. For instance, the decisions of planners in Week 6 deal in general with transforming big tasks into smaller ones without digging deeply in execution details. At this week, planners usually try to remove major constraints and to ensure important pre-requisites can be met. As we get closer to the execution week, planners' start to consider the detailed execution requirements that need to be made ready to allow the execution of tasks. In this context, planners' decision on weekly work load, and therefore the corresponding weekly capacity, is taken at the end of week 2, just before the week 1 being the execution week. Thus, the planner needs to decide on the corresponding weekly capacity based on the available work load that appears at the end of week 2. Note that the work load that appears at the end of week 2 may change during week 1 for three reasons: (1) because some of the perceived ready activities may not be ready, (2) since some of the NotReadyCMR activities could not be made ready to execution, and (3) because new activities, not already captured by the plan, may emerge. Therefore, the planner refers to the Load that appears at the end of week 2 to decide on the capacity needed at week 1. This Load is directly related to the

Table 2-1: Project Profiles

Profiles	1	2	3	4	5	6	7	8	9
Description	Base Case	High R, RR	Low R, RR	High P, NR	Low P, NR	Low NBR, High N	High NBR, Low N	Best Scenario	Worst Scenario
R (±0.15)	0.50	**0.70**	**0.30**	0.50	0.50	0.50	0.50	**0.70**	**0.30**
RR (±0.15)	0.70	**0.85**	**0.55**	0.70	0.70	0.70	0.70	**0.85**	**0.55**
P (±0.15)	0.50	0.50	0.50	**0.70**	**0.30**	0.50	0.50	**0.70**	**0.30**
NR (±0.15)	0.50	0.50	0.50	**0.70**	**0.30**	0.50	0.50	**0.70**	**0.30**
NBR (±0.15)	0.40	0.40	0.40	0.40	0.40	**0.20**	**0.60**	**0.20**	**0.60**
N (±0.15)	0.50	0.50	0.50	0.50	0.50	**0.70**	**0.30**	**0.70**	**0.30**

number of Ready activities which include the Ready Activities and the Not Quite Ready activities. The CNMR activities are excluded at this point and the New activities did not appear yet. Therefore, the planner, while deciding on the weekly capacity, needs to estimate the number of activities that will be Ready Ready out of the Ready, Not Quite Ready, and expected New Activities. Since the number of New activities is not known at week 2, the number of resources (capacity) is presented as a function of Ready and Not Quite Ready activities as presented in equation 1.

Number of Resources Assigned (capacity) = (Ready Activities + NotReadyCMR Activities) x CAP Eq. (1)

According to equation (1), the planner seeks an optimum CAP that balances the expected weekly Load and the corresponding Resources assigned. Note that Resources are assumed to be indistinctive and that each activity requires 1 resource only. Consider this case for clarification: at the end of week 2, the number of perceived Ready activities is 7 and the number of NotReadyCMR activities is 4; a total of 11 activities that may be executed during week 1. During the week, one of the Ready activities turned to be Not Ready, 2 of the NotReadyCMR activities are made Ready Ready, and 2 New activities appear with one made Ready Ready. Therefore, a total of 9 activities is actually ready and can be executed. In this case, had the planner chosen a CAP of 1 at the end of Week 2, he would have been prepared 11 Resources for the needed weekly capacity, thus over allocating two resources and increasing the incurred costs. The optimum CAP decision in this scenario is 0.8 (0.8*11=9 with the rounding). While any guess under this optimum value would result in under allocation of resources and delayed task, a greater guess would result in over allocation of resources and extra costs.

Therefore, the planner's decision is essential to balance capacity and load during the execution of the lookahead plan. Nonetheless, the planner's decision is an extra cause of variability in this process that affects the production on site. To address this important factor, four capacity planning types are investigated in this study against the nine project profiles presented in Table 1. Table 2 defines the different planning types investigated in this study. The first two planning types: the "Constant CAP" and "Variable CAP" fall under the category of "Un-Informed Planners" where the planner either sizes the crew needed according to the overall available work load that appears at the end of Week 2, or randomly select the corresponding crew size. Note that this variability appears whenever the planner uses his/her common sense to decide on the crew size based on his/her perception of project performance and dynamics. A normal distribution is used in this study to represent this random variability. The other two planning types: the "Average CAP" and "Metrics' Average" belong to the "Informed Planners" category. "Average CAP" planners decide on the weekly CAP based on the average of previous optimum CAP values; whereas, "Metrics' Average" planners decide on the weekly CAP based on the average of previous RR, NR, NBR, and N.

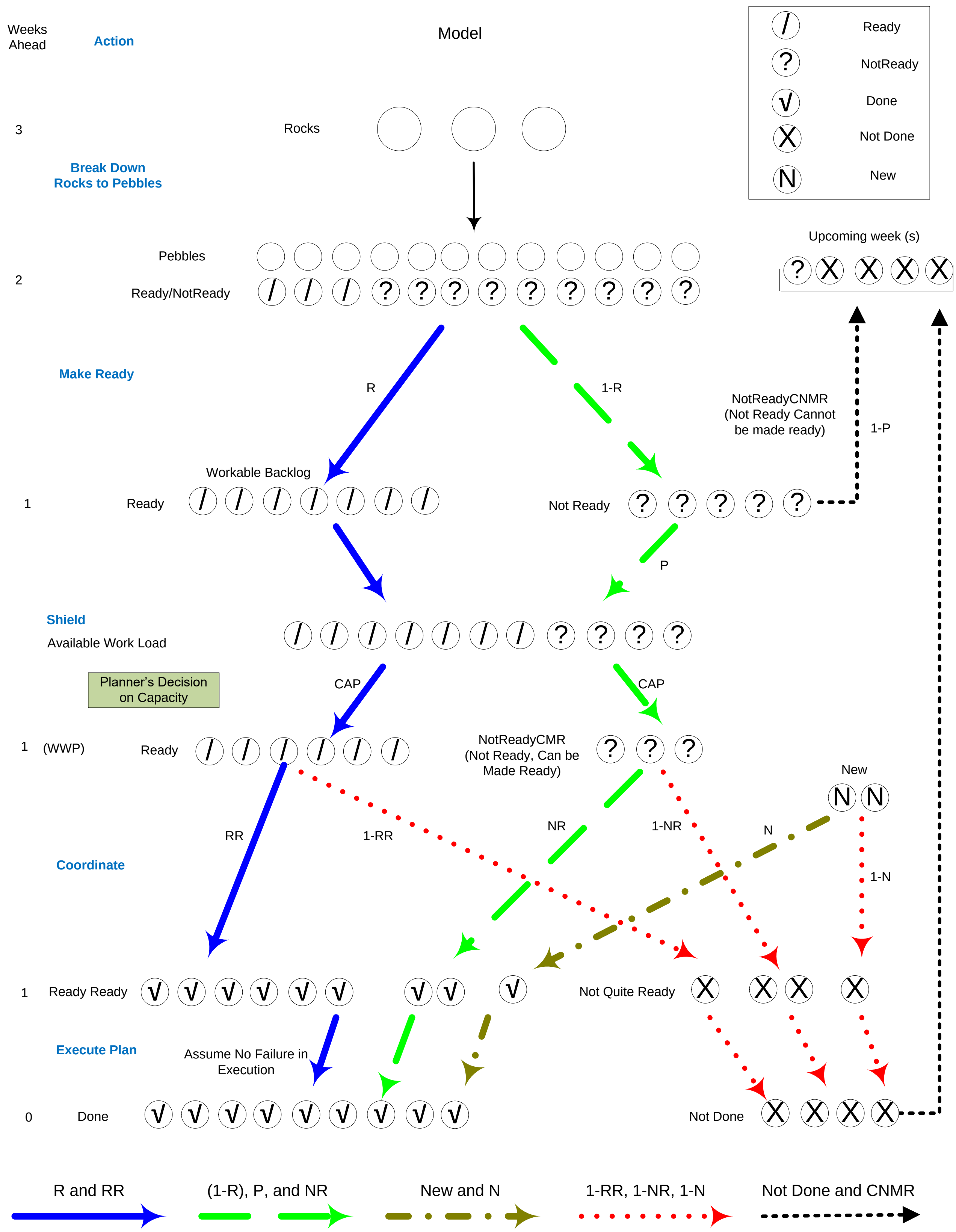

Figure 2-1: Lookahead Plan

Table 2-2: Planning Types

Category	Planning Type	Description	CAP Calculated
Un-informed Planners	Constant CAP	Planners are assumed to choose a CAP of 1.0 every week regardless of project performance.	CAP_n=1.0
	Variable CAP	Planners are assumed to variably select weekly CAPs following a normal distribution of mean 1 and standard deviation of 0.15.	CAP_n=Normal(1,0.15)
Informed Planners	Average CAP	Planners choose weekly CAPs according to the average of previous optimum CAP values.	CAP_n=avg (CAP_{opt})
	Metrics' Average	Planners choose weekly CAPs according to the average of previous RR, NR, NBR, and N.	CAP={($Ready_n$*RR_{avg}+$NotQuiteReady_n$*NR_{avg}+ AllInitialActivities (excluding those falling back from the previous week)*NBR_{avg}*N_{avg})} /WWP

2.2 Outputs of the simulation experiments

The model is simulated for 500 times to ensure a Confidence Index (CI) higher than 0.95. The CI results are provided in Appendix B. The output of the simulation runs are as follows:

1. **Duration**: Total Duration of the Project in weeks, averaged over 500 simulation runs for each combination of profile and planning type.
2. **CRRV+** (cost attribute): The cumulative number of resources (equivalent to the chosen capacity in each week), over-allocated to ready tasks, during the entire project duration, averaged over 500 simulation runs.
3. **CRRV-** (time attribute): The cumulative number of resources (equivalent to the chosen capacity in each week), under-allocated to ready tasks, during the entire project duration, averaged over 500 simulation runs.
4. **Capacity to Load Ratio:** This is an indirect metric that measures the ratio of planned capacity (equivalent to assigned resources) to the executed load at a certain week. CLR reflects the quality of the capacity planning for a certain week and it is calculated as follows:

$$CLR = \frac{Planned\ Capacity}{Executed\ Load} \quad \text{Eq. (2)}$$

5. **Capacity Planning Quality (CPQ)**: It is the deviation of the CLRs, during all project weeks, from the value of 1 where planned capacity equalizes executed load (the optimum case). Equation 3 is used to calculate the CPQ of the project for a certain profile. Note that the CPQ value is averaged over 500 simulation runs for each combination of profile and planning type.

$$CPQ = \sqrt{\sum_{i=1}^{i=n} \frac{(CLR_i - 1)^2}{n}} \quad \text{Eq. (3)}$$

3 RESULTS AND DISCUSSION

This section presents the results of the conducted simulation experiments. Nine different project profiles shown in Table 1 are simulated according to four different planning types highlighted in Table 2. The results are averaged over 500 simulation runs and presented in Figures 2 and 3. Section 3.1 analyses the effects of the planning method on project's cost and duration for different profiles, whereas, section 3.2 discusses the quality of the capacity planning under different project scenarios.

3.1 Cost and Time Performance

The first aspect tackled in this study is the effect of planning type on project's cost and time performance for different project's profiles. Figure 2 highlights the averaged CRRV results for each combination of profile and planning method. Recall that CRRV+ is a cost metric that reflects the cumulative number of resources over-allocated to tasks over the entire project's duration. However, CRRV- is a time metric that reflects the cumulative number of resources under-allocated to tasks over that same period. Accordingly, CRRV+ indicates an increase of incurred costs wasted on over-allocated capacity; while CRRV- reflects a failure to complete certain tasks on time due to resource shortages; thus affecting the overall duration of the project.

Figure 2 shows that the values of CRRV+ and CRRV- are sensitive to the planning type as well as the project's characteristics. As for the overall cost performance of the project, it is noted that the "Variable CAP" planning methods leads to the highest CRRV+ values for all profiles. It means that the random selection of needed capacity contributes to an increase of incurred costs where the deviation from the optimum CAPs is at its maximum. The "Constant CAP" planning method leads to better CRRV+ values especially for profiles 2, 4, and 8. Therefore, fixing the capacity planning method leads to a decrease of incurred costs especially if the project's profile favors the making ready process as in profiles 2, 4, 6, and 8. Thus, the deviation from the optimum CAP in the case of "Constant CAP" planning type is less than the deviation witnessed in the case of "Variable CAP" planning type for all project's profiles.

The informed planning types, "Average CAP" and "Metrics Average", show better cost performance throughout the project than the un-informed planning types. Nonetheless, it is noted that when it comes to extra incurred costs, the performance of informed planners is much better than un-informed planners, specifically for projects having troubles with the making ready process as in profiles 3, 5, 7, and 9 (top dashed lines). Thus, planners who are aware of their project's performance are more likely to avoid over-allocation of resources and therefore they can escape extra incurred costs. It is worth noting that "Metrics Average" planners show the best cost performance with the lowest CRRV+ values as indicated in Figure 2.

As for the time performance of the project, the "Variable CAP" planning type leads to the highest CRRV- values for all project's profiles, especially for profiles favoring the making ready process as in profiles 2, 4, and 8 (bottom solid lines in Figure 2). In other words, randomly selecting needed capacity may under-estimate the expected load keeping ready activities starving for resources. However, the "Constant CAP" planning type has the best time performance for all project's profiles manifested by the lowest CRRV- values. This is because the constant CAP of 1.0 is leading to an over-allocation of resources in the majority of project' weeks regardless of the corresponding profile. Therefore, "Constant CAP" planners are more likely to have the best project's duration, but at the penalty of extra incurred costs. Nonetheless, this cost penalty is aggravated in the case of projects having a problem in the making ready process as in profiles 3, 5, 7, and 9.

Informed planners have similar CRRV- results for all profiles. The scored values are slightly higher than the "Constant CAP" values; however, better than the "Variable CAP" results. Accordingly, informed planners may slightly under estimate the needed capacity in some weeks throughout the project without significantly affecting the project's duration. In this regard, informed planners seems to strike the best balance between incurred costs and the time performance of the project.

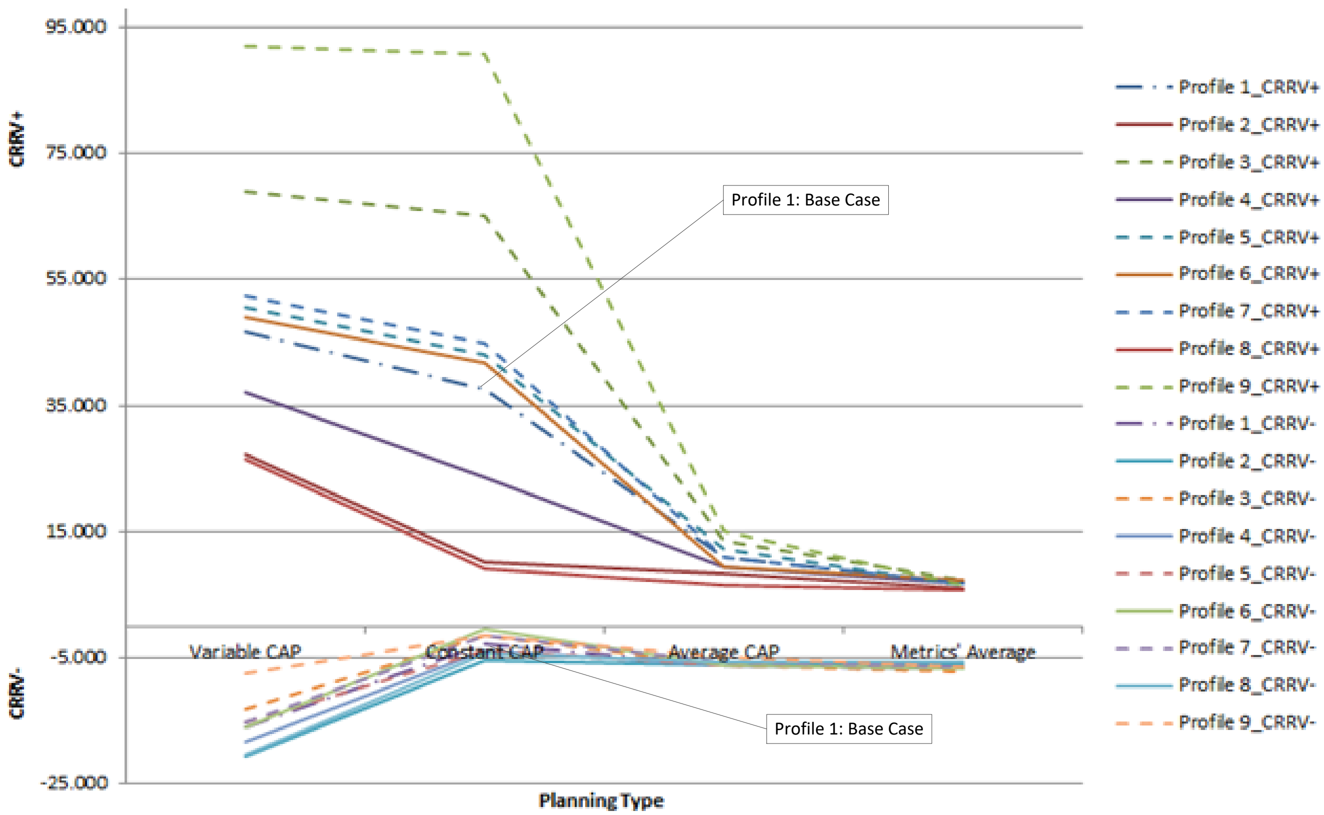

Figure 3-1: Cost (CRRV+) and Time (CRRV-) attributes for different planning methods and profile types

3.2 Quality of Capacity Planning

Another aspect of project's performance investigated in this study is the quality of capacity planning throughout the project's duration. So in addition to time and cost performance discussed in Section 3.1, this section examines the quality of capacity planning by monitoring the values of the CPQ metric introduced in section 2.2. Figure 3 presents the CPQ values (bars) of the project for each combination of profile and planning type. Recall that CPQ reflects the quality of capacity planning by measuring the deviation of weekly CLRs from the optimum value of 1.0. Figure 3 also shows the percentage of weeks with over-allocation of resources by plotting the corresponding graphs (lines) for each combination of planning method and project's profile.

The "Variable CAP" planning method results in the highest CPQ values for all profiles. Therefore, the added variability from the planner's side negatively affects the quality of capacity planning regardless of project's characteristics. "Constant CAP" planning method contributes to better CPQ values if compared to the "Variable CAP" method. However, "Informed Planners" have much better CPQ values for all project's profiles reflecting better capacity planning throughout the project. Nonetheless, "Metric's Average" planners, who are informed about their project's performance parameters, strike the best CAPs regardless of project's profile and scored the best CPQ values.

For "Constant CAP" planning method, the majority of weeks witnesses over-allocation of resources even with profiles 2 and 8 that have high rates of making ready tasks. Whereas, the "Variable CAP" method witnesses lower number of weeks with over-allocation especially in the cases of profiles 2 and 8; however, at the cost of higher CPQ values. In other words, although the number of weeks with over allocation is lower, the deviation from the optimum CAP is higher. As for "Average CAP" planners, the number of weeks with over-allocation depends on profiles' characteristics. This number is high for profiles 3, 5, 7, and 9 (solid lines) that represents projects with problems in the making ready process, and relatively low for profiles 2, 4, 6, and 8 (dashed lines) where better project performance is realized. Interestingly, for "Metrics' Average" planning type, the number of weeks with over-allocation of resources is almost equal for all profiles with values slightly below 50%. It means that planners who are thoroughly informed about their project's performance are closer to reach optimum CAPs and their capacity planning is balanced throughout the project regardless of its characteristics.

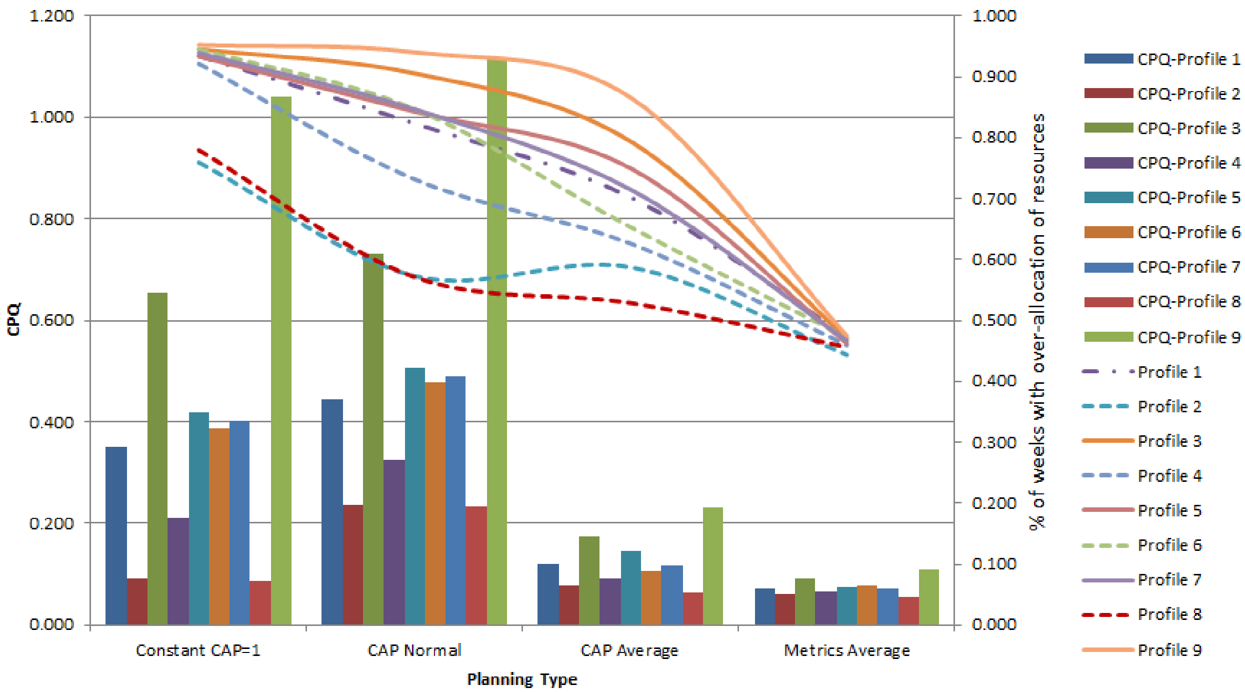

Figure 3-2: CPQ and Percentage of Weeks with Over-Allocation of Resources for each Profile According to Four Planning Types

3.3 Expert panel results

The study engages a list of experts in the field of construction and production planning to investigate the reliability of simulation outputs. The expert panel consists of five full time professors in worldwide esteemed institutions as well as two practitioners with more than ten years of professional experience in an international company. The experts were asked to respond to three hypotheses and six questions as highlighted in Table 3.1. The results of the questionnaire are summarized in Figures 3.3 and 3.4. Figure 3.3 presents the answers to the hypotheses that aim to point out the need of enhancing capacity planning; whereas, Figure 3.4 presents experts' responses to questions related to the study findings.

Figure 3.3 shows that all panel participants acknowledge the effects of project's variability on capacity planning. Nonetheless, they acknowledge that the planning method adopted is by itself an extra cause of variability in the project. Almost 70% of respondents think that accessing project's previous planning data can help enhance future capacity planning. These results show that addressing capacity planning is a crucial step towards enhancing project's time and cost performance, where tailoring capacity planning method to project's characteristics sounds promising.

Figure 3.4 summarizes experts' responses concerning the study findings. All participants agree that Un-Informed planners significantly affect project's time and cost performance. For "Variable CAP" planners, all respondents agree that variably choosing capacity each week affects both the time and cost performance of the project. For "Constant CAP" planners, all participants see that continuously over-allocating weekly capacity enhances project's time performance, but at the expense of higher costs wasted on idle resources. As for "Informed Planners", 70% of participants agree that informed planners have higher capacity planning quality manifested by low CPQ results. Finally, 70% of participants think that "Metrics Average CAP" planners are least affected by project's profiles, and therefore, 80% of participants considers "Metrics Average CAP" planners to be the closest in terms of providing a balanced delivery of resources throughout the project's duration.

Table 3-1: Hypotheses and Questions Addressed by the Expert Panel

Questionnaire Item	Description
Hypothesis 1 (H1)	Variability in the lookahead process hinders capacity planners from striking the best capacity size during execution weeks.
Hypothesis 2 (H2)	The type of capacity planning is an extra cause of variability in the lookahead process.
Hypothesis 3 (H3)	Planners who have access to project's previous capacity planning data (planned vs. actual) can perform better in terms of capacity planning.
Question 1 (Q1)	Planners who randomly choose their weekly CAPs have inferior time and cost performance as demonstrated by the high CRRV+ and CRRV- values for all project's profiles.
Question 2 (Q2)	Planners providing extra resources than the expected load, as in the case of "Constant CAP" planners, have better time performance but at the expense of extra incurred costs, as demonstrated by the high CRRV+ and low CRRV- values.
Question 3 (Q3)	Informed planners have a better balance between incurred costs and project's duration demonstrated by the low CRRV+ and CRRV- values.
Question 4 (Q4)	Informed planners are more likely to strike a better balance between work load and capacity as demonstrated by the low CPQ results.
Question 5 (Q5)	"Metrics Average" planners are more likely to be less prone to project's characteristics since they are thoroughly informed about the corresponding parameters, as demonstrated by the lowest CPQ results.
Question 6 (Q6)	"Metrics Average" planners are more likely to provide a balanced delivery of resources throughout project's weeks, as highlighted by the

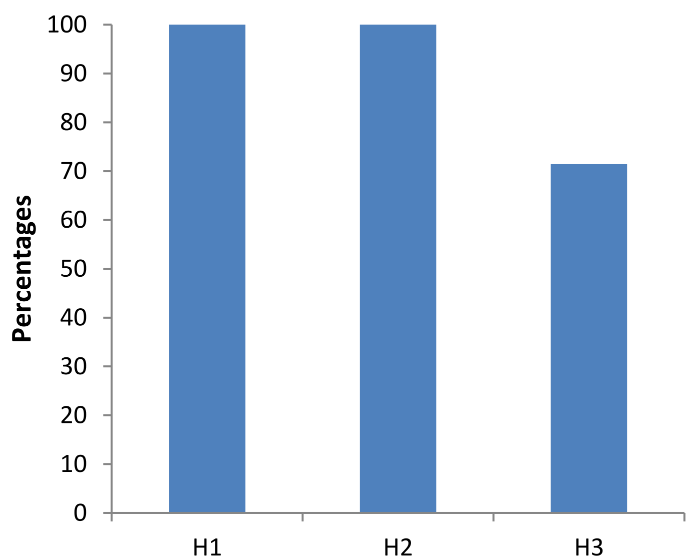

Figure 3-3: Responses to Hypotheses

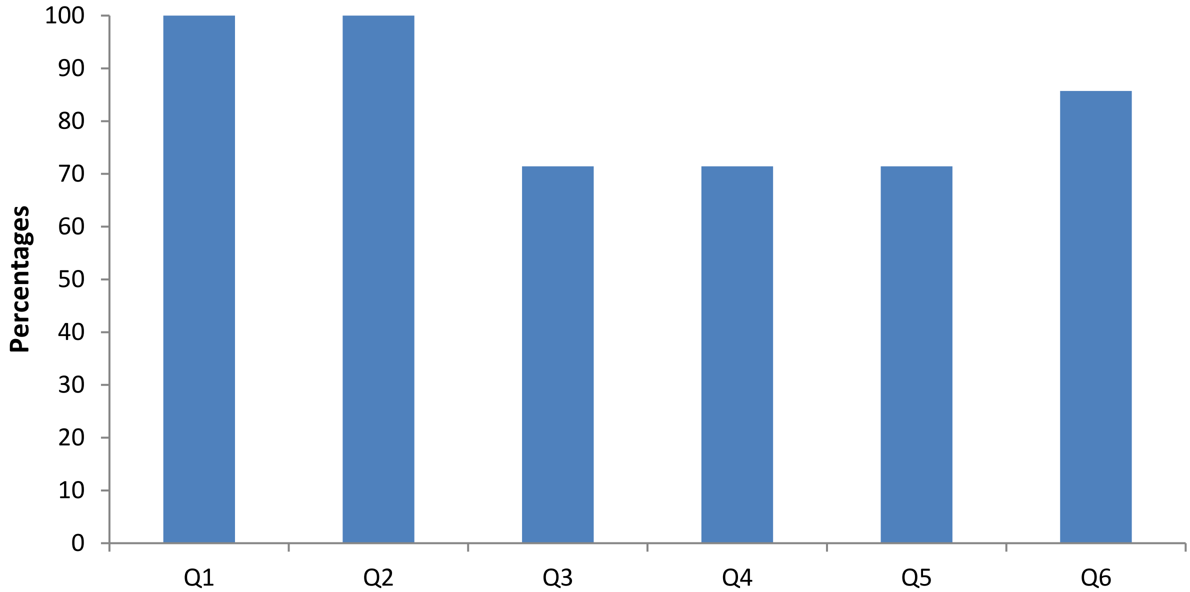

Figure 3-4: Responses to Questions

4 CONCLUSIONS

This paper investigates the role of planners in matching load and capacity during the lookahead process. Since the weekly load resulting from the making ready process is not stable and has stochastic characteristics, planners are urged to act against this variability every time they decide on the weekly capacity. Otherwise, they will be over or under-allocating resources and therefore affecting project's performance. Nonetheless, deciding on weekly capacity has a margin of guess especially that planners expect new activities to emerge in the execution week, a percentages of not ready tasks transformed into ready activities, and a percentage of ready tasks turning into not ready ones.

The choice of capacity is linked to Ready and NotReadyCMR activities that appear at the end of week 2 as presented in Equation 1. At this moment, the CNMR activities are excluded and the New activities did not appear yet. Therefore, the planner, while deciding on the weekly capacity, needs to estimate the number of activities that will might be Ready Ready out of the Ready, Not Quite Ready, and expected New Activities. Accordingly, the perceived Ready and NotReadyCMR activities are multiplied by a CAP factor in order to size the capacity needed in the coming week.

To cover several project's scenarios, nine different project's profiles are investigated against four different planning types. While each profile has stochastic parameters' values, each planning type refers to a method followed by the planner to decide on weekly capacities. Profile 1 is intended to be a base case with parameters' values ranging in the average zones, whereas profiles 2 to 9 have modified values that either enhance the making ready process (profiles 2, 4, 6 and 8), or hinder it (profiles 3, 5, 7 and 9). As for the planning types, two categories of planners are introduced: Informed and Un-Informed Planners. Informed Planners are those who know their project's performance by either following weekly optimum CAPs (the case of "Average CAP" planners), or by following the values of R, RR, NR and N (the case of "Metrics' Average" planners). However, Un-Informed planners either follow a constant CAP of 1.0 throughout the entire project or randomly select its values every week.

The results of the 500 simulation runs came as follows: the time and cost performance of the project is affected by the planning type adopted by the planner. Nonetheless, these effects are inflated if the project is witnessing a low making ready process as in profiles 3, 5, 7 and 9. Cost wise, the "Variable CAP" and "Constant CAP" planning methods leads to extra incurred costs wasted on over-allocated capacity reflected by high CRRV+ values. However, the "Average CAP" and "Metrics' Average" planning types have reduced incurred costs for all project profiles reflected by low CRRV+ values. Time wise, the best performance is scored by "Constant CAP" planners with the least CRRV- results, closely followed by "Average CAP" and "Metrics Average" planners. However, this slightly better time performance comes at the penalty of high incurred costs wasted on over-allocated capacity. "Variable CAP" planners scored higher CRRV- values and leads to an increase of project's duration as well as the corresponding incurred costs.

Therefore, informed planners are more likely to guaranty a balanced supply of resources throughout the project's duration regardless of project's profile. Nonetheless, they are more likely to strike the best balance between incurred costs and project's duration where proper allocation of resources is achieved. In this regard, "Metrics Average" planners are most likely to have the least amount of cost wasted on over-allocated capacity where less than 50% of project's weeks, for all profiles, witnessed a slight over-allocation of resources.

Concerning the CPQ results, which reflect the quality of capacity planning by measuring the deviation of weekly CLRs from the value of 1.0 (optimum value), it is noted that differences appear among planning types. The "Variable CAP" planning method contributes to the highest CPQ values for all profiles. Therefore, the random selection of weekly CAPs based on subjective perceptions of weekly needed capacity has negative effects on capacity planning. It results in unstable supply of resources and un-balanced production throughout the project. The "Constant CAP" planning method, where the planner fixes a CAP value of 1.0 for all weeks, has better CPQ results than the "Variable CAP" method. Thus, stabilizing the supply of resources has positive effects on the quality of capacity planning; however, at the expense of extra incurred costs where the majority of weeks are witnessing over-allocated capacity as highlighted in Figure 3. The two informed planning types, "Average CAP" and "Metrics Average" have much better CPQ results than the un-informed planners. Moreover, the "Metrics Average" planners score the best CPQ results for all profiles, where the deviation from the optimum capacity size is less prone to project's characteristics.

As for the number of weeks witnessing over-allocation of resources, only "Metrics' Average" planners were able to maintain a low over-allocation percentages regardless of project's performance as shown in Figure 3. "Constant CAP" planners were over-allocating capacity for the majority of project's weeks, even for Profiles 2 and 8 that have high number of tasks made ready. "Variable CAP" planners have on average less weeks with over-allocation if compared to "Constant CAP" planners, especially that the variability in choosing the CAP values is sometimes leading to resource shortages. The "Average CAP" planners successfully reduced the number of weeks having over-allocation for profiles 2, 4, 6 and 8; however, this number increased for projects having troubles in the making ready process (Profiles 3, 5, 7 and 9).

In this regard, this study shows that informed planners have more chance to reach the optimum capacity needed during project's weeks than un-informed planners. Moreover, "Metrics Average" planners are more likely to have the best cost and time performance throughout the entire project's duration regardless of its corresponding characteristics. Therefore, investing in understanding project's performance by following weekly R, RR, P, NR, NBR, and N values, is expected to enhance the quality of capacity planning throughout the project's execution and to reduce wasteful expenditure on idle resources. Moreover, since these parameters are different for each construction trade, each team can follow trade's specific parameters values to decide on the corresponding capacity.

Finally, this paper shows that informed planners, specifically "Metrics' Average" planners, can act against the unstructured variability rooted in the lookahead process by filling the knowledge gap related to their project performance characteristics, as recommended by Ben-Haim & Laufer, (1998). Accordingly, filling the gap between what planners perceive about their project's performance and what the actual performance is can help planners better size the needed capacity every week while avoiding extra incurred costs or delayed tasks.

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6 APPENDICES

6.1 Appendix A: Abbreviations and terminology used throughout the paper

Term	Description
Rocks	Tasks at the level of detail of processes in the project
Pebbles	Tasks at the operation level
Ready	Number of pebbles that are made ready during WK1
Not Ready	Number of tasks that are Not-Ready but have a chance to become ready some time prior to their scheduled execution
NotReadyCNMR	Number of Not-Ready tasks that can be made ready during the execution week
NotReadyCMR	Number of tasks that are not ready but can be made ready during the execution week
New	Number of New tasks not originally anticipated in the lookahead plan
R	Percentage of pebbles that are made ready during WK1
RR	Percentage of Ready tasks that are actually ready or unconstrained
P	Percentage of tasks that are Not-Ready but have a chance to become ready some time prior to their scheduled execution
NR	Percentage of Not-Ready tasks that will be made ready during the execution week
NBR	Ratio of New tasks at WWP to Pebbles at the end of WK2
N	Percentage of New tasks made ready during the execution week
CAP	Capacity factor multiplied by Ready Activities and NotReadyCMR Activities

6.2 Appendix B: Confidence Index of Simulation Runs

		Planning Types			
Profile		**Constant**	**Normal**	**Average CAP**	**Metrics' Average**
1	Duration	0.998	0.998	0.998	0.998
	CPQ	0.994	0.986	0.983	0.981
2	Duration	0.998	0.997	0.997	0.998
	CPQ	0.980	0.983	0.994	0.990
3	Duration	0.996	0.999	0.997	0.997
	CPQ	0.984	0.985	0.990	0.989
4	Duration	0.999	0.998	0.998	0.998
	CPQ	0.991	0.982	0.986	0.994
5	Duration	0.998	0.997	0.998	0.998
	CPQ	0.980	0.987	0.985	0.990
6	Duration	0.997	0.998	0.999	0.998
	CPQ	0.990	0.992	0.984	0.983
7	Duration	0.998	0.998	0.997	0.998
	CPQ	0.984	0.982	0.979	0.984
8	Duration	0.997	0.996	0.997	0.997
	CPQ	0.984	0.983	0.977	0.980
9	Duration	0.997	0.997	0.997	0.996
	CPQ	0.994	0.992	0.979	0.989

7 REFERENCES

Aziz, R. F., & Hafez, S. M. (2013). Applying Lean Thinking in Construction and Performance Improvement. *Alexandria Engineering Journal*, 679-695.

Ballard, G., Kim, Y., Jang, J., & Liu, M. (2007). *Roadmap to Lean Implementation At Project Level.* Austin, Texas: Construction Industry Institute (CU).

Ballard, G., & Howell, G. (1998). Shielding Production: Essential Step in Production Control. *Journal of Construction Engineering and Management*, 11-17.

Ben-Haim, Y., & Laufer, A. (1998). Robust Reliability of Projects with Activity-Duration Uncertainty. *Journal of Construction Engineering and Management*, 125-132.

Bennett, N.D., et al. "Characterising performance of environmental models." Environmental Modelling & Software 40 (February 2013): 1-20.

Dvir, D., Raz, T., & Shenhar, A. J. (2003). An Empirical Analysis of the Relationship between Project Planning and Project Success. *International Journal of Proejct Management*, 89-95.

Hamilton, M., & Gibson Jr., G. (1996). Benchmarking Preproject-Planning Effort. *Journal of Management in Engineering*, 25-33.

Hamzeh, F., & Langerud, B. (2011). Using Simulation to Study the Impact of Improving Lookahead Planning on the Reliability of Production Planning. *Proceedings of the 2011 Winter Simulation Conference*, (pp. 3436-3447).

Gonzalez, V., Alacron, L., & Molenaar, K. (2009). Multiobjective Design of Work-In-Process Buffer for Scheduling Repetitive Building Projects. *Automation in Construction*, 95-108.

Gonzalez, V., Alacron, L. F., Mundaca, F., & Jose, B. (2010). Improving Planning Reliability and Project Performance Using the Reliable Commitment Model. *Journal of Construction Engineering and Management*, 1129-1139.

Gupta, A., Gonzalez, V., & Miller, G. (2012). Understanding the Relationship between Productivity and Buffers in Construction: A Simulation-Based Case. *Proceedings for the 20th Annual Conference of the International Group for Lean Construction.*

Law, Averill M. . "A TUTORIAL ON DESIGN OF EXPERIMENTS FOR SIMULATION MODELING." *Proceedings of the 2014 Winter Simulation Conference. A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, eds.* 2014.

Laufer, A., Shapira, A., Cohenca-Zall, D., & Howell, G. A. (1993). Prebid and preconstruction planning process. Journal of construction engineering and management, 119(3), 426-44.

Martinez, Julio C. . "Methodology for Conducting Discrete-Event Simulation Studies in Construction Engineering and Management." *JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT © ASCE* 136, no. 1 (2010): 3-16.

Serrador, P., & Turner, R. (2015). What is Enough Planning? Results From a Global Quantitative Study. *IEEE Transactions On Engineering Management*, 462-474.

Junnonen, J.-M., & Seppanen, O. (2004). Task Planning as a Part of Production Control. *Proceedings of the 12th Annual Conference of the International Group for Lean Construction*, (pp. 1-11).

Tommelein, I. D., Riley, D., & Howell, G. A. (1998). Parade Game: Impact of Work Flow Variability on Succeeding Trade Performance. *Proceedings IGLC '98.* Guaruja.

Lindhard, S., & Wandahl, S. (2012). On The Road to Improved Scheduling - Fitting Activities to Capacity. *RICS COBRA 2012*, (pp. 1604-1612). Las Vegas.

Sakamoto, M., Horman, M. J., & Thomas, H. R. (2002). A Study of the Relationship between Buffers and Performance in Construction. *10th Annual Conference of the International Group for Lean Construction.* Gramado, Brazil.

Park, M., & Pena-Mora, F. (2004). Reliability Buffering for Construction Projects. *Journal of Construction Engineering and Management*, 626-637.

Lee, S., Pena-Mora, F., & Park, M. (2006). Reliability and Stability Buffering Approach: Focusing on the Issues of Errors and Changes in Concurrent Design and Construction Projects. *Journal of Construction Engineering and Management*, 452-464.

Kim, S.-C., Kim, Y.-W., & Park, C.-J. (2008). Introduction of Workforce Database System for Effective Production Planning. *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, (pp. 833-838).

S. AbouRizk, Role of simulation in construction engineering and management, J. Constr. Eng. Manag. ASCE 136 (2010) 1140–1153.

R. Axelrod, Advancing the art of simulation in the social sciences, in: J.P. Rennard (Ed.), Handbook of Research on Nature Inspired Computing for Economy and Management, Idea Group Publishing, Hershey, USA, 2006, pp. 90–100.

K. Dooley, Simulation research methods, in: Joel Baum (Ed.), Companion to Organizations, Blackwell, London, 2002, pp. 829–848.

Farook R. Hamzeh, Issa Saab, Iris D. Tommelein, & Glenn Ballard (2015). Understanding the role of “tasks anticipated” in lookahead planning through simulation. *Automation in Construction.* 49, 18-26.

Robert E. Shannon (1998). Introduction to the art and science of simulation. *Proceedings of the 1998 Winter Simulation Conference D.J. Medeiros, E.F. Watson, J.S. Carson and M.S. Manivannan, eds.*

Andrei Borshchev (2013). Multi-method modeling. *Proceedings of the 2013 Winter Simulation Conference R. Pasupathy, S.-H. Kim, A. Tolk, R. Hill, and M. E. Kuhl, eds*.

N.D. Bennett et al., (2013). "Characterizing performance of environmental models," Environmental Modelling & Software, vol. 40, pp. 1-20.

R. G. Sargent, "Verification and validation of simulation," in Proceedings of the 2011 Winter Simulation Conference, Phoenix, 2011, pp. 183–198.