# RATIONAL COMMITMENT MODEL: IMPROVING PLANNING RELIABILITY AND PROJECT PERFORMANCE

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## ABSTRACT

Reliability of planning commitments at operational level is one of the key factors to improve project performance. The Last Planner System (LPS™) is a tool designed to improve planning reliability in construction industry, however, the improvements in planning reliability are often limited due to the fact that the decision-making processes in construction, including those related to planning commitments, are mainly based on experience and intuition. The Rational Commitment Model (RCM) presented in this paper is a tool that helps to overcome this situation by introducing decision-making aids based on analysis of field data, which allows developing more reliable planning commitments using statistical models. RCM allows forecasting planning commitments for short term-periods using field production data such as labor available, buffer size, and planned progress. Several case studies have demonstrated the RCM forecasting capabilities and its practical use to improve reliability of planning commitments and project performance. The RCM also contributes to solve the well-known workload-capacity problem and provides useful insight into lean production performance issues.

## KEY WORDS

Lean Production, Rational Commitment Model, Planning Reliability, Statistical Models.

## INTRODUCTION

How planning decisions are made to manage variability in construction projects is one of the most relevant issues in construction (Laufer et al, 1994). Variability is a well-known problem in construction on which there is much ongoing research (Ballard, 1993; Alarcón and Ashley, 1999; Tommelein et al, 1999; among others). Several authors have recognized that traditional project management does not consider the non-linear and dynamic nature of projects (Bertelsen, 2003; McGray et al, 2002). In construction, this

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yields non-realistic planning outputs (e.g. schedule and budget), since planning process is based on the wrong notion that projects are static. Therefore, construction planning leads to poor management decisions since variability is not explicitly incorporated within planning process, contributing to deteriorate project performance (González, 2008).

Current construction planning mainly depends on intuition and experience to deal with variability. As a result, planning has not been effectively managing projects and has not been able to accurately predict how a project should be executed (Laufer et al, 1994), imposing unrealistic expectations on the production process or failing to manage it altogether, increasing system variability (Tommelein et al, 1999).

The Last Planner System (LPS™) a production planning and control system based on lean production principles was developed to overcome these limitations in construction planning (Ballard, 2000). LPS™ promotes improved planning reliability, which provides a stable production environment in projects and reduces the negative impact of variability. In LPS™, activities in work plans should only be committed if they can be performed, i.e. they meet critical criteria (Ballard, 2000). The activities critical criteria are: 1) they are well defined, 2) the right sequence is selected, 3) the right amount of work is selected, and 4) the work selected is practical or sound, that is, can be done according to the availability of construction preconditions (design, materials, workers, space, prerequisites, etc.).

Frequently construction projects outsource most of the work to subcontractors, and commitments are arranged between contractors and subcontractors. Contractors should strive to obtain reliable commitments from the subcontractors. However, many of them assign work to subcontractors based on their intuition and experience, resulting in unreliable commitments (Sacks and Harel, 2006). Although LPS™ represents a sounder planning framework, it does not deliver an entirely rational planning process mainly at operational level where the work is executed.

This paper proposes the Rational Commitment Model (RCM), a new decision decision-making tool based on lean principles, which uses statistical models to obtain more reliable commitment planning at an operational level improving project performance. RCM allows forecasting commitment planning for short term-periods using information such as workers, buffers, and planned progress.

The following sections in this paper describe the theoretical and practical foundations of the RCM. Then, the RCM effects on planning reliability and project performance, and the load-capacity matching problem, in several case studies are addressed.

## RELATIONSHIP BETWEEN PLANNING RELIABILITY AND PROJECT PERFORMANCE

Recently, several researchers have demonstrated a positive and strong relationship between planning reliability and project performance, where the impact of a better planning reliability has been measured through the improvements over productivity at project level where the LPS™ has been applied (González et al, 2008a; Liu and Ballard, 2008).

Due to the limited evidence linking the changes in planning reliability with changes in productivity at the activity level, an in-detail study was carried out by González et al

(2008a). These authors proposed reformulation of the indicator for planning reliability used by LPS™, Percentage of Plan Complete (PPC), to carry out meaningful productivity comparisons at the activity level. Therefore, a complementary 'activity-based' planning reliability index, called Process Reliability Index (PRI) was developed. PRI is defined as:

$$PRI_{i,j} = \left( \frac{AP_{i,j}}{PP_{i,j}} \right) \times 100 \quad (1)$$

Where:

$PRI_{i,j}$= Process Reliability Index for week i and activity j (%), i=1…n; j=1...m.

$AP_{i,j}$= Actual Progress for week i and activity j, i=1…n; j=1...m.

$PP_{i,j}$= Planned Progress for week i and activity j, i=1…n; j=1...m.

PRI represents a planning reliability index at the activity level. PRI does not compare actual to planned cumulative progress because it is based on partial measurements (i.e. weekly progress), which can vary from a measurement period to another. PRI measures the degree of activity planning effectiveness from a commitment standpoint. To measure planning reliability, PRI values range between 0 and 100% (González et al, 2008a).

A study of the relation between PRI and productivity at activity level by González et al (2008a) showed that higher PRI levels lead to improved productivity. This confirms the assumption that increasing planning reliability improves project performance at activity and project level. In this sense, LPS™ acts at project level, producing planning reliability improvements not only at that level, but also at activity level to get improvements in a project as a whole.

## MATCHING LOAD AND CAPACITY

Matching load with capacity is critical for productivity of production systems in construction (Ballard, 2000; Thomas and Horman; 2006, among others). According to Ballard (2000), load is the amount of work in a specified time which is assigned through planning to crews. In contrast, capacity is the amount of work a crew can do at any point in time with given tools and work methods for actual site conditions. The problem in matching load with capacity is that, for instance, actual resource utilization and production rates of crews are production variables many times a-priori unknown, given their changeable behavior caused by wastes in conventional practices (Ballard, 2000), leading to a poor balance between load and capacity and losses of productivity.

Ballard (2000) states whatever the precision of load and capacity estimates. Load can be changed to match capacity by delaying or accelerating workflow. Capacity can be changed to match load by decreasing or increasing resources. However, the preference seems to be for adjusting load. LPS™ is instrumental to match load with capacity by pulling materials and/or information into a production process or activity, only if the activity is able of doing the work, i.e., what activity needs and in the needed amounts are actually available. (see Hopp and Spearman (2000) for more details about pull systems).

However, LPS™ can loss effectiveness to match load with capacity. This issue can emerge when critical criteria for work assignments are not correctly defined and met. Several reasons can explain it. First, it is difficult to accurately determine the right amount of work to perform by crews in work plans based only on the experience of project personnel since it can be not very reliable and subjected to several biases (Spetzler and Von Holstein, 1975, McGray, et al, 2002). In contrast, if historical data is used, it may not be accurate enough, due to changes in current construction practices (Ramírez et al, 2004).

Second, it is not easy to see if work is practical or sound (i.e. all construction preconditions are ready for crews to perform work) for work plans. For instance, the number of necessary site-workers supplied by subcontractors to a specific project depends on business demands, i.e. labor requirements from other projects. If there are projects with better site conditions where the subcontractor job is more profitable, his preference will be change the labor resource until site conditions are improved in the original project. Thus, labor resource can constantly be changed from one project to another (in a weekly or even daily basis) (Sacks and Harel, 2006). As a result, labor resources are not ready or available whenever it is required and in the correct amount in a project. Something similar can happen, for instance, with the buffer management.

These issues address several limitations related to how matching load with capacity in the LPS™, suggesting to change the way in which this process is carried out.

## INTUITION AND RATIONALITY FOR MAKING COMMITMENTS PLANNING

Most of the people tend to describe and understand the world around through simplistic models of reality. This may be due to the difficulties that human beings have to manipulate large amount of information, developing in many cases mental twirls (Spetzler and Von Holstein, 1975). In construction, this kind of phenomena is prevalent in its decision-making processes given the complexity and dynamic nature of the projects, which can lead to erroneous and poor decisions (Bertelesen, 2003; McGray et al, 2002). For instance, a common practice for estimating labor productivity, and accordingly, construction schedules and budget, is to simply assume that work progress is related to the number of workers in a perfect linear form. A simple exercise using historical data of any project would demonstrate that is not true, since if one constructs this linear relationship using real site information will be discovered that it is imperfect (for instance, see the construction of simple linear regression model). Then, project decisions based on simple heuristics can lead to over or underestimation of project objectives, which can have harmful effects on performance.

As mentioned earlier, LPS™ defines several criteria that should be met to perform work plans. One of the most difficult criteria to be met is to define the right amount of work. The previous discussion would suggest that the decision-making process for defining this criterion can be oversimplified leading to suboptimal definition of work plans. Then, this may result in inaccurate amount of work performed by contractors.

On the other hand, contractors should strive to obtain reliable commitments from the subcontractors since this relationship is opposing and non-collaborative. Thus, work plans are imposed or "pushed" to subcontractors independent of the planning process state and/or site conditions (Sacks and Harel, 2006). Therefore, if contractors oversimplified several of the steps to state work plans, which are based on their intuition and experience; it is very probable that this will lead to planning instability and unreliable work plans. Subcontractors' reaction will probably be to continuously change their own estimations, and even, resources allocation (Sacks and Harel, 2006). So, this interaction between contractors and subcontractor will systematically produce unreliable work plans and further deteriorate of project performance.

To overcome the prior issues, a methodological framework is proposed that strives to replace the intuition, experience and oversimplification, which is the basis for the current planning practices related to LPS, for a framework that relies on rational assumptions to obtain more reliable work plans.

## RATIONAL COMMITMENT MODEL FRAMEWORK

RCM is based on lean principles focusing specifically on: 1) reduction of variability in production by improving planning reliability, and 2) promoting a pull production system by matching load with capacity. We will describe the conceptual and mathematical framework, as well as the RCM process validation and its application methodology.

### CONCEPTUAL AND MATHEMATICAL FRAMEWORK

Previously, González et al (2008b) proposed a conceptual framework to the RCM in which progress can be predicted using historical information such as labor, buffers and planned progress. Mathematically, RCM uses multiple linear regression (MLR) to formulate the model, which assumes the following form: $y= \beta_0+ \beta_1x_1+ \beta_2x_2+\ldots+ \beta_nx_n+\varepsilon_i$,, where y is the dependent variable, $x_i$ are independent variables, $\beta_i$ are the corresponding parameters of the dependent variables, and εi is the random error. The expression for predicted progress in RCM is:

$$PRP = \beta_0 + \beta_1 W + \beta_2 WIPBf + \beta_3 PP \tag{2}$$

Where:

*PRP*= is the Predicted Progress for an activity in the short-term planning horizon (typically one week). Units may be $m^2$, $m^3$, linear-meters, houses, apartments, etc.

*W*= is the number of workers for an activity in a short-term planning horizon. W is the sum of workers in the planning horizon. For instance, if the planning horizon is 1 week of 5 days, and there are 5 worker-days, W is 25 workers.

*WIPBf*= is the available work-in-process buffer for an activity at the beginning of the planning horizon. For instance, if the planning horizon is one week, the WIPBf for the painting activity, which depends on the wall-stucco activity, is the available work produced by the wall-stucco activity, measured at the beginning of the week, before painting begins. Units may be $m^2$, $m^3$, linear-meters, houses, apartments, etc.

*PP*= is the planned progress for an activity in a short-term period (one week). Units may be $m^2$, $m^3$, linear-meters, houses, apartments, etc.

RCM uses MLR models to estimate the activity progress at the operational level, based on historical data. Only significant variables are selected in the models using the coefficient of determination ($R^2$) and the P-value. Also, the prediction accuracy of RCM is evaluated using two indicators: Process Reliability Index (PRI), defined earlier and Commitment Confident Level (CCL), which is defined as:

$$\text{Predicted / PlannedCCL}_{i,j} = \left(1 - \left(\frac{\text{Predicted / PlannedPRI}_{i,j} - \text{ActualPRI}_{i,j}}{\text{ActualPRI}_{i,j}}\right)\right) \times 100 \quad (3)$$

Where:

*Predicted/Planned* $CCL_{i,j}$= Commitment Confidence Level for week i and activity j (%) for both predicted and planned PRI.

*Predicted* $PRI_{i,j}$= Predicted Process Reliability Index for week i and activity j. Predicted PRI replaces AP in Eq. (1) by PRP using the RCM.

*Planned* $PRI_{i,i}$= Planned Process Reliability Index for week i and activity j. Its value is estimated by a decision-maker given a planned progress according to his own experience which can be progressively influenced by the RCM outputs.

*Actual PRIi,j*= Actual or Real Process Reliability Index for week i and activity j. Actual PRI is computed using Equation (1).

CCL measures the activity commitment accuracy for the predicted progress which compares the predicted and the actual PRI. Similarly, it relates the planned and actual PRI. RCM methodology and nomographs to easily apply it by project managers were initially proposed by González (2008) and González et al (2008b). Finally, the conceptual and mathematical framework of the RCM was tested and validated earlier by González et al (2008b).

## RCM Role For Improving Planning Reliability And Project Performance

The use of statistical models in the RCM to describe the production behavior in projects will inherently increase planning reliability at activity level. On the other hand, by means of increasing planning reliability is possible to improve performance in projects at two levels: project and activity. Therefore, improvements on planning reliability and performance (labor productivity) at activity level will lead to enhance the same thing at project level. In fact, common sense suggests that if a set of activities individually increase its planning reliability and this set structures the entire project, then it is expected that the planning reliability at project level is improved getting a better performance at project level. As result, RCM action to improve planning reliability and project performance starts at activity level to finally act at project level.

## Matching Load And Capacity With The RCM

The capability to match load with capacity is other characteristic of the RCM. Two mechanisms are basically applied by the RCM to match load with capacity: 1) Fix either load or capacity and develop sensitive analyses for the free variable according to actual production conditions, and 2) Study the effect of several construction preconditions that can prevent the performance of an activity to mitigate its impact.

In the first mechanism, load as planned progress can be fixed analyzing the level of capacity as worker-weeks required to meet the amount of work planned. Other variable involved in the estimation of load is the planned PRI which a decision-maker can include to visualize the impact of the planning reliability over capacity levels. In contrast, if capacity is limited, i.e. the number of worker-weeks is constrained by the subcontractor's needs; the level of load is adjusted to certain amount of work given a planned PRI. Obviously, it can be a third option in which both load and capacity can be simultaneously matched according to the decision-makers preferences. Also, the extent for which both load and capacity can change week to week is determined by the information statically processed in the RCM.

In the second mechanism, RCM explicitly manipulates several construction preconditions as number of workers and buffer levels. The first precondition is analyzed according to the first mechanism. Otherwise, the analysis of buffer levels is one the most interesting characteristics of the RCM studied earlier by González et al (2008b). For instance, the influence of the buffer size (WIP Bf) over labor productivity given the planned progress (load) and planned PRI can be analyzed. A larger buffer results improved labor productivity, and therefore in a reduced number of worker-weeks. On the other hand, for the same number of worker-weeks, a higher planned progress can be expected with a larger buffer because of the improvement in labor productivity. i.e. capacity is increased. As a result, RCM suggests other production variables to solve the load-capacity matching problem.

Therefore, the decision-making process to match load with capacity is also more reliable using the RCM overcoming its current limitations.

## CASE STUDIES ANALYSIS OF RCM IMPACTS

Two repetitive building projects as cases studies were analyzed using site data from González et al (2008b)' research where the RCM was actively applied in decision-making process, with the support of a computer prototype. Next a description of the RCM to improve planning reliability and project performance and solve the load-capacity matching problem is presented.

### CASE STUDY A: IMPROVING PLANNING RELIABILITY AND PROJECT PERFORMANCE

Plastering activity in a multi-family residential building was selected as case study A to analyze how improving planning reliability through the RCM could increase project performance. Figure 1 shows data and evolution of RCM application in case study A.

In this case should be noted that MLR models were mainly specified with a combination of W and WIPBf variables, being key on-site production pieces during implementation of the RCM. Figure 1 shows the evolution of the RCM application during 17 weeks. It is shown the 'Planned Progress', 'Predicted Progress' and 'Actual Progress'. Three different periods can be distinguished according to Figure 1: 1) 'No-predictions period' in which is only collected data as input for the RCM; 2) 'Predictions/no-decisions period' in which planning predictions were performed, but manager do not use the RCM outputs to make decisions since technical decisions rest on his own experience and project team experience; and 3) 'Predictions/decisions period' in which manager and project team use information generated by the RCM to make planning decisions, leading to relevant improvements in activity performance. The analysis is focused on the last two periods.

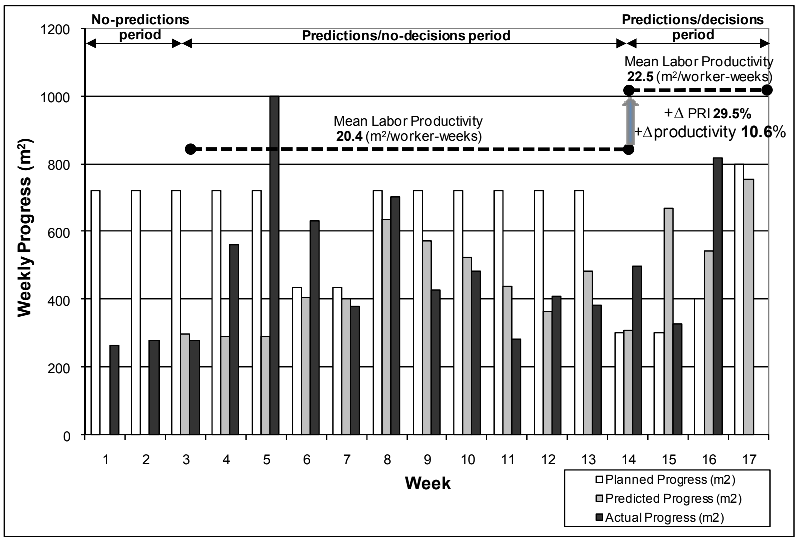


Figure 1: RCM Application Evolution Case Study A.

During the 'Predictions/no-decision period', the predictive capability of the RCM was demonstrated. After this, project personnel were willing to use the RCM to make planning decisions, which happened starting from the $14^{th}$ week as shown in Figure 1. Due to the fact that from $11^{th}$ week activity progress was a function of W and WIPBf, an active intervention over these variables was decided. By using the RCM at the beginning of $14^{th}$ week, sensitivity analyses to study the effect of WIPBF over W were performed for the following four weeks of Plastering activity. In such a way, the project manager determined to slow down the activity pace not involving a higher number of W during $14^{th}$ and $15^{th}$ weeks. On the other hand, during these weeks a larger WIP Bf was deliberately created keeping a low W level. It was determined that a WIPBf size closer to 2000 $m^2$ could maximize labor productivity in order to achieve PP levels of 800 $m^2$ with W levels closer to 31 worker-weeks. Then, during $16^{th}$ and $17^{th}$ the numbers of W was increased taking advantage of a higher buffer size according to the estimated values.

A rough analysis of data from Figure 1 shows that the mean actual PRI for the 'Predictions/no-decisions period' (from $3^{rd}$ to $13^{th}$ week) and 'Predictions/decisions period' (from $14^{th}$ to $17^{th}$ week) is 70.55% and 100% respectively. Otherwise, the effect over labor productivity for the same periods was estimated as the ratio between actual progress and worker-weeks. Mean labor productivity for the 'Predictions/no-decisions period' and 'Predictions/decisions period' was 20.4 ($m^2$/worker-weeks) and 22.5 ($m^2$/worker-week). In other words, planning reliability was increased by 41.0% and productivity was improved by 10.3% (see Figure 1). A detailed survey shows even better results. Particularly, $14^{th}$ and $15^{th}$ weeks produced a larger WIPBf which is resulted in productivity improvements the following weeks. Therefore, an upper improvement is observed in $16^{th}$ and $17^{th}$ weeks. The mean actual PRI between $3^{rd}$ and $15^{th}$ weeks is 72.49% and between $16^{th}$ and $17^{th}$ weeks is 100%, reaching a planning reliability improvement of 38.0% in the last ones. Similarly, the mean labor productivity between $3^{rd}$ and $15^{th}$ weeks is 20.6

($m^2$/worker-weeks) and between 16th and 17th weeks is 27.0 ($m^2$/worker-weeks), stating a productivity improvement of 31.0%. On the one hand, the improvement in labor productivity is explained by a better planning reliability during the last two weeks, and the direct actions at operational level over production variables as W and WIPBf using the RCM. On the other hand, there is an unexpected growth of labor productivity explained by the psychological effect of higher WIPBf levels over subcontractor and crews given better production conditions, improving their performance to get a higher profitability (González, 2008; Sacks and Harel, 2006).

Also, it is important to notice that the predicted progress by RCM is more accurate than the planned progress by manager given the mean predicted and planned CCL shown in Table 4 (81.6% and 64.7% respectively). Besides, a closer analysis shows that planned progress from 3rd to 13th week is commonly overestimated against actual progress (see Figure 1). Once project personnel relies on the RCM prediction capabilities (starting from 14th), planning reliability is significantly improved. During the last four weeks predicted and planned CCLs were similar, doing progressively that project personnel supported their planned objectives with predicted objectives from RCM. By doing so, planning decisions were more rationally made.

## CASE STUDY B: MATCHING LOAD WITH CAPACITY

Floor-Wall Ceramic activity in a multi-storey building was selected as case study B to determine the influence of the RCM in the load-capacity matching problem. In this case, labor resource was a boundary condition that prevented the activity production speed. In such a way, the MLR models were mostly a function of W which allows a more accessible and easier analysis of capacity. By using previous definitions, load can be understood as planned progress and capacity as actual progress. Fig. 5 shows a summary of RCM implementation results on the case study B.

Figure 2 describes the evolution of the RCM application during 8 weeks, showing the 'Planned Progress', 'Predicted Progress' and 'Actual Progress' with their respective values. Also, two periods were identified: 1) 'Unmatched Load/Capacity period' where there is no a clear balance between planned and actual progress; and 2) 'Matched Load/Capacity period' where there is more balanced planned and actual progress levels. In theory, a perfect matching between load and capacity should be imply equal planned and actual progress levels, i.e. actual PRI levels equal to 100%, and a balanced used of labor resources according to planned progress.

Figure 2 shows that planning predictions after the 3th week, when enough production data was available to produce reliable MLR models. It is also observed that during the 'Unmatched Load/Capacity period' (from 1st to 4th week) prevails the overestimation of planned progress which is a common behavior observed in the first weeks of every activity analyzed, even when RCM produces the first predictions. In the 'Matched Load/Capacity period' (from 5th to 8th week) is observed that planned and actual progress were more balanced, since RCM predictions mainly showed that previous planning commitments were overestimated. Thus, manager used RCM outputs to develop sensitive analysis to determine better planned progress level according to the available labor resource. During the 7th week the project manager determined that planning decisions should completely rely on the RCM outputs, having a better balance between the planned, predicted and actual progress. However, the activity execution is finished during the 8th week. An in-deep examination of data in Figure 2 shows that the mean actual PRI for the 'Unmatched Load/Capacity period' and the 'Matched Load/Capacity period' were 55.9% and 68.9% respectively, showing an obvious improvement of 13.0% in planning reliability promoted by the RCM, but also an increased balance between load and capacity during the period in which RCM is used.

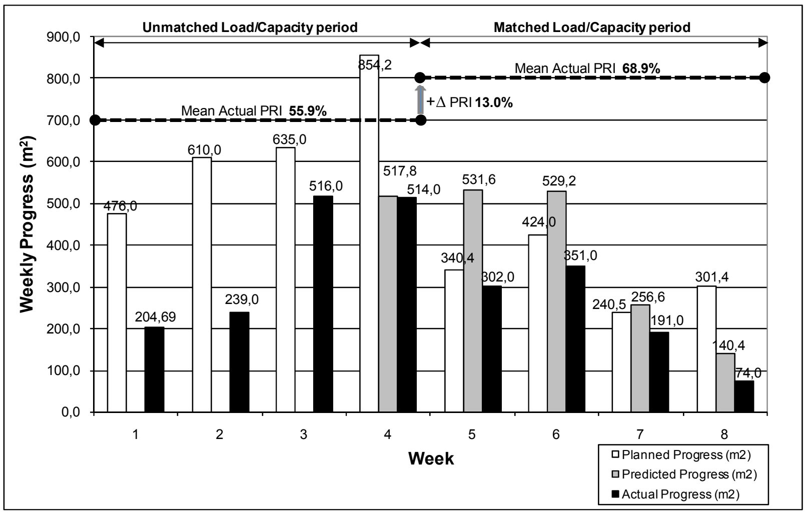


Figure 2: RCM Application Evolution Case Study B.

In addition, the evolution of planned progress and actual worker-weeks was analyzed by using the correlation coefficient (R). The purpose was to determine if load and capacity defined by the labor level were effectively matched with the RCM. So, the higher R-value, the better is the load-capacity matching. R-values analyzing the relationship between planned progress and actual worker-weeks for the periods shown in Figure 2 were computed. R-values for the 'Unmatched Load/Capacity' and 'Matched Load/Capacity' periods were 0.72 and 0.84 respectively. On the other hand, R-values from '1st to 4th' weeks and from '5th to 8th' weeks (period in which is effectively used the RCM) were 0.73 and 0.80 respectively. It is observed that R-values are better in those periods where RCM was applied. This confirms that its application helped to match load with capacity, being applied by manager to specifically balance the labor levels to planned progress.

In brief, RCM allows effectively matching load with capacity by using explicitly its predictions outputs, promoting a pull mechanism in which production planning is subjected to production system state. Accordingly, planned estimates are defined and suited to available resources which should be balanced during the construction phase.

## CONCLUSIONS

A new decision-making tool for planning decisions at operational level, we call Rational Commitment Model (RCM) is proposed in this paper. RCM is based on lean production principles and can predict commitment planning using production information such as workers, buffers and planned progress, being processed through statistical models. In this research, a reasonable amount of site evidence is provided to demonstrate the validity of the RCM. Fundamentally, two theoretical issues of the RCM were tested in this paper: 1) Its capability to improve planning reliability and project performance; and 2) Its capability to match load with capacity. The evidence provided a relevant support to state that RCM allows effectively dealing with them. In particular, the RCM showed its capacity to improve planning reliability and project performance measured as labor productivity. Even though the number of activities analyzed in every project did not allow analyzing the overall performance impact of improving planning reliability at project level (i.e. the improvement of the general project productivity), the assumptions addressed in this research should be enough to accept that the RCM has a key effect on project performance. On the other hand, the RCM effectiveness to match load with capacity rests in its mechanism pull that allows defining the load as planned progress according to production system conditions, e.g. labor level which yields a determined capacity as actual progress. This mechanism is based on the RCM capability to perform an accurate and transparent decision-making process for the contractor and subcontractor personnel, where several productions variables can be simultaneously analyzed.

On the other hand, the RCM can be characterized as a practical and simple tool to take planning decisions. For instance, input data used by the RCM is not different to those gathered in construction projects, simplifying the data collection process. Other example is the use of multivariate linear regression models which is a common topic of engineering education, therefore, most of engineers in projects should be familiarized with these statistical techniques.

However, several limitations and questions should be solved to improve not only the mathematical specification of the RCM but also practical issues of its on-site implementation. Several of these topics are part of ongoing research currently carried out by some of the authors. Finally, the RCM demonstrates that more rational decisions aided by analytical-statistical tools allow achieving for a more reliable and accurate planning process with positive impacts over project performance. Intuition and experience will always be an important part of the decision-making process in construction. In such a way, tools as the RCM can improve the ‘intuition’ and ‘experience’ abilities of construction decision-makers for the construction industry business.

## REFERENCES

Alarcón, L.F. and Ashley, D. B. (1999). Playing Games: Evaluating the Impact of Lean Production Strategies on Project Cost and Schedule. *Proceedings 7th Annual Conference of International Group for Lean Construction,* University of Berkeley, California, U.S.A., July 26th -28th.

Ballard, G. (2000). The Last Planner System of Production Control. *PhD's Thesis*, School of Civil Engineering, Faculty of Engineering, The University of Birmingham, Birmingham, U.K.

Ballard, G. and Howell, G. (1998). Shielding Production: Essential Step in Production Control. *J. Const. Engr. Mgmt., ASCE,* 124, (1), pp. 11-17.

Ballard, G. (1993). Lean Construction and EPC Performance Improvement. Alarcón, L. F. (ed), *Lean Construction*, A.A. Balkema, The Netherlands, 497 pp.

Bertelsen, S. (2003). Complexity – Construction in a New Perspective. *Proceedings 11th Annual Conference of International Group for Lean Construction,* Virginia Tech, Blacksburgh, Virginia, U.S.A, 16-17 July.

González, V., Alarcón, L.F. and Mundaca, F. (2008a). Investigating the Relationship between Planning Reliability and Project Performance. *Prod. Plan. Control*, 19, (5), 461-474.

González, V., Alarcón. L.F., Maturana, S., Bustamante, J.A. and Mundaca, F. (2008b). Work-In-Process Buffer Management using the Rational Commitment Model in Repetitive Projects. *Proceedings 16th Annual Conference of International Group for Lean Construction,* Manchester, UK, 16-18 July.

González, V. (2008). Uncertainty Management in Repetitive Building Projects using Work-In-Process Buffers. *PhD's Thesis,* Department of Construction, Engineering and Management, Engineering School, Pontificia Universidad Católica de Chile, Santiago, Chile.

Hopp, W. J. and Spearman, M. L. (2000). *Factory Physics: Foundations of Manufacturing Management*, 2nd ed., Irwin/McGraw-Hill, Boston.

Koskela, L. (2000). An Exploration Towards a Production Theory and its Application to Construction. *PhD's Dissertation*, VTT Building Technology, Helsinki University of Technology, Espoo, Finland.

Laufer, A., Tucker, R. L., Shapira, A. and Shenhar, A. J. (1994). The Multiplicity Concept in Construction Project Planning. *Const. Mgmt. and Econ.*, 12, (1), 53-65.

Liu, M. and Ballard, G. (2008). Improving Labor Productivity through Production Control. *Proceedings 11th Annual Conference of International Group for Lean Construction,* Manchester, U.K., 16-18 July.

McGray, G. E., Purvis, R. L. and McCray, Coleen G. (2002). Project Management Under Uncertainty: The Impact of Heuristics and Biases. *Proj. Mgmt. J.,* 33, (1), 49-57.

Ramírez, R. R., Alarcón, L.F., and Knights, P. (2004). Benchmarking System for Evaluating Management Practices in the Construction Industry. *J. Mgmt. Engr.*, *ASCE*, 20, (5), 110-117.

Sacks, R. and Harel, M. (2006). An Economic Game Theory Model of Subcontractor Resource Allocation Behaviour. *Const. Mgmt. and Econ.,* 24, (8), 869–881.

Spetzler , C. S. and Von Holstein, C. S. S. (1975). Probability Encoding in Decision Analysis. *Mgmt. Sc.*, 22, (3), 340-358.

Tommelein, I. D., Riley, D. R. and Howell G. A. (1999). Parade Game: Impact of Work Flow Variability on Trade Performance. *J. Const. Engr. Mgmt., ASCE,* 125, (5), 304-310.