The Asian Review of Civil Engineering
ISSN: 2249 - 6203 Vol. 6 No. 2, 2017, pp.23-30

Time Optimization Technique Using Reliable Commitment Model

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Abstract - Construction is a very complex process and nearly every single project is unique. The resulting number of parts, relative lack of standardization, multiple participants and constraining factors make construction projects a difficult endeavour. Adding to this complexity is the high degree of interdependency inherent to the construction process. Complexity can be defined as "something made up of closely connected parts which are difficult to explain or understand, or a number of different parts intricately related". Due to the inherent complexity, uncertainty, and variability of the construction process, it is important to study the root causes of time buffer used to protect against those challenging characteristics. Reliable Commitment Model, RCM, a new decision-making tool, using statistical models to develop more reliable work plans at the operational level in repetitive projects. RCM increases planning reliability, reduces variability, and promotes a continuous workflow with short waiting times. The main objective is to study the potential improvement on project performance when using RCM to manage WIP buffers at the site or operational level. Worker weeks and process progress are used as the main performance measures in a repetitive building project. RCM analyses the problems of planning process at the operational level shows that one of the most important reason for non-completion of weekly plans in repetitive project is the lack of WIP. RCM predicts the process progress by using variables such as Worker weeks, WIP buffer and planned progress, using Multiple Linear Regression (MLR) at the operational level.
Keywords: **Construction Projects, Variability, WIP Buffers, Multiple Linear Regression, Reliable Commitment Model**

I. INTRODUCTION

Construction is a very complex process and nearly every single project is unique. The resulting number of parts, relative lack of standardization, multiple participants and constraining factors make construction projects a difficult endeavour. Adding to this complexity is the high degree of interdependency inherent to the construction process. Complexity can be defined as "something made up of closely connected parts which are difficult to explain or understand, or a number of different parts intricately related" This complexity is combined with the ever-growing economic demand to deliver projects more quickly while minimizing costs, resulting in uncertainty as a characteristic component of construction and often leading to variation.

Uncertainty can be generally defined as a set of possible outcomes where probabilities are assigned to each possible outcome. However, uncertainty as it pertains to the research here is a "presence of doubt, changeability, and lack of assurance or reliability" While variability or variance in statistics is a measure of how far a set of numbers is spread out, variation is defined as the difference between what was planned and what actually happened (Wambeke et al. 2011). Further, variability as discussed in this research pertains to the propensity for variation due to the inherent uncertainty in construction projects.

Construction personnel involved with the project have a natural tendency to compensate for the uncertainty by adding buffer to task durations to absorb the resulting variations in the work plan. In fact, standard practice is to try to build as much buffer as possible into the duration of tasks for which one is responsible. This results from lacking a mechanism for coordination. Buffers can be seen as wasteful because they do not directly add value to a construction project even though they allow downstream operations to continue. One definition of waste includes "anything that is different from the minimum quantity of equipment, materials, parts, and labour time that is absolutely essential for production". The minimum is however not necessarily the optimum or most efficient way to do things. Due to the inherent complexity, uncertainty, and variability of the construction process, it is important to study the root causes of time buffer used to protect against those challenging characteristics. Once the root causes are identified, methods for addressing the most problematic areas and an understanding of how construction personnel at various levels of management allocate the time buffer can be developed. Construction managers can then take effective steps towards addressing those causes, managing uncertainty, allocating time buffer where it is needed most and reducing the overall associated time buffer in construction projects.

II. OBJECTIVES

The primary goal of the research is to better understand the allocation of time buffer to construction project task durations. González et al. (2010a) recently introduced Reliable Commitment Model, RCM, a new decision-making tool based on lean production principles, which uses statistical models to develop more reliable work plans at the operational level in repetitive projects.

Forecasting work plans for short-term periods by using information about number of workers every week, WIP buffer, and planned progress. RCM thus increases planning reliability, reduces variability, and promotes a continuous workflow within a short term planning horizon. This thesis focuses on the behaviour and influence of WIP buffer, which is one of the RCM variables, on system performance.

The main objective is to study the potential improvement on project performance when using RCM to manage WIP buffers at the site or operational level. Worker weeks and process progress are used as the main performance measures in a repetitive building project.The secondary goal is to promote a change in the construction buffer management culture by improving understanding of the buffer impact on project performance and by using a practical approach at the operational level.

III. SCOPE OF THE STUDY

Construction is a very complex process and nearly every single project is unique and uncertain. The design and assembly of objects fixed in place is characterised by site construction, unique design and temporary work teams. The traditional management approach for work plans defines activities and schedule work that will be done, in terms of what should be done from a master plan, with no real consideration for what a crew is actually able to do.The ability of a work team to reliably perform work depends on the stability of the so-called workflow. In construction, workflow can be characterized by crews moving from location to location and completing the work that is prerequisite to starting work by the following. In turn, a stable workflow depends on construction preconditions such as resources (design, components and materials, workers, equipment, and space) and prerequisites (completed work of upstream activities) that should be available whenever they are needed. However, workflow variability could negatively affect crews' performance, causing idle time or ineffective work

Buffers have been commonly used as a production strategy to protect construction processes from the negative impact of variability. Traditional management practices in construction rely primarily on intuition and experience, which lead to superficial analysis and erroneous or poor decisions.To overcome this, this study proposes a new site methodology for managing work-in-process (WIP) buffer in repetitive projects, on the basis of the reliable commitment model (RCM). RCM is a decision making tool based on lean principles, which uses statistical models to develop more reliable work plans at the operational level. RCM helps to manage WIP buffer in work plans by using site information and planning reliability indicators that result in improved project performance, such as worker weeks and process progress.

IV. LITERATURE REVIEW

The purposes of this literature review are to study the background of construction research pertaining to variation, variability, and variance, to define variation for this research and to identify causes of variation and their relation to work flow and productivity. Lean Construction was also studied as part of this literature review. Also to study the existing research pertaining to the definition of buffer, the function of buffer, and the types of buffer, to provide a foundation for defining and identifying the causes of buffer and their relation to productivity, work flow, and variation. Further, the purpose of this literature review is to study factors in construction literature which affect project performance as well as labour productivity as they are hypothesized to be closely related to the causes of buffer. An introduction to Reliable Commitment Model (RCM), a decision tool based on lean principles is also included. RCM develops more reliable work plans at operational level using statistical model.

A. Definition of Variation

There are several different definitions of variability or variation as it pertains to labour productivity. Rilett (1998) defined variability as the variance associated with a component or end product specification in construction projects. Tommelein *et al.* (1999) defined work flow variability as the standard deviation from an expected average. Radosavljevic and Horner (2002) defined variance in construction labour productivity as standard deviation, a measure of dispersion from the mean. Thomas et al. (2002) calculated variation of productivity as the average of the absolute value of the difference between daily productivity and the baseline productivity. Howell et al. (2004) measured variability of work flow by comparing the tasks assigned (those tasks that "will" be done), to those completed (what "did" get done). Koskela (2000) defined variability as random variation in the processing times or arrival of inputs

B. Buffers

Buffers in construction management are the extra time added into a time estimate to keep a project on track. The purpose of this leeway is risk management. Buffers allow the project manager to be able to account for unseen situations without having to change the coordination of a project in a major way. It is often used to compensate for uncertainty and protect against workflow variation. Time buffer is the difference between the scheduled or planned task duration and minimum duration the task should take based on an optimum or baseline productivity. This baseline productivity is the best productivity a contractor can achieve on a given project and typically occurs when the material, equipment, information, and plan are adequate (Sakamoto et al. 2012).

It is fundamental to categorize construction buffers. Hopp and Spearman's (2008) divide buffers to inventory buffer, time buffer, and capacity buffer, in view of the fact that other categorizations of buffers are more or less add-ups to Hopp and Spearman's. For example, Russell et al. (2013) add plan and financial buffers. Another distinguished view of buffer types is defined by Goldratt (1997), he divides buffers into project buffer, feeding buffer, and resource buffer, and builds a dynamic buffer management to ensure the critical path for completing a project.Construction literature focuses on five main types of buffer. Hopp and Spearman (2008) list inventory, capacity, and time as three types of buffer. Ballard and Howell (1995) introduced a fourth type of buffer called plan buffer. The literature also discusses the use of cost contingency as a financial buffer. These five types of buffer are described in Table I.

TABLE I TYPES OF BUFFERS

Type of Buffer	Definition
Inventory	Buffers of physical material stockpiles (Horman and Thomas 2005). Large buffers of inventory can lead to congestion which impedes performance, but material stockpiles which are too low can lead to stopped, slowed, or disrupted production.
Capacity	Buffers of additional manpower and/or equipment provided to an operation beyond the anticipated need for completion (Horman and Thomas 2005). Additional capacity provides an operation the ability to rapidly respond to situations caused by uncertainty and variability. Too much capacity buffer can also result in inefficient labour and equipment use.
Plan	Buffers that are inventories or backlogs of workable assignments (Ballard and Howell 1995). Plan buffer provides alternative tasks for crews to perform that keep them working in the right sequence when the main tasks planned cannot be performed or whenassignments are completed sooner than expected.
Time	Buffer that takes the form of additional time added into a task to protect against uncertainty and to absorb variation. The concept of float is one such use of time buffer and is seen in the Critical Path Method. Float provides some flexibility in determining start dates for activities without delaying the project’s completion (Alves and Tommelein 2004). A similar example is the use of a deliberate pause or time lag inserted between step in an operation (Horman and Thomas 2005). Lee et al. (2006) points out time buffers have been mainly used as a contingency such as adding a percentage of the activity duration at the end of the activity to accommodate uncertain and variable conditions.
Financial	Money in the construction project budget reserved to pay for unforeseen design or construction costs (Risner 2010).

The construction industry demands increasingly shorter project schedules. This situation pushes contractors to permanently struggle to reduce project execution time. The situation is aggravated by uncertainty resulting from urgent requirements, non-consistent construction sequences, lack of coordination in the supply chain, project scope changes, poor quality, among other factors. The combined effect of uncertainty and complexity in a project produces variability in construction systems (Horman, 2000)

C. Work-In-Process Buffer

Work-In-Process buffer can be defined as the difference between the cumulative progress of two consecutive and dependent activities or processes that characterises work units ahead of a crew that will perform. WIP is more apparent in repetitive building projects.

Vicente Gonzalez (2013) states that by using a buffer, a production process can be isolated from the environment and the processes depending on it, and the negative impact of variability can be reduced in the production chain (Koskela, 2000). Current practices like using material inventories, time and cost contingencies, excess labour and equipment capacity, etc., are examples of how projects deal with variability in intuitive and informal ways. This could be explained by the lack of sound methodological approaches to systematize variability management. Recently, some researchers and practitioners have proposed new approaches to manage variability in construction (Alarcon and Ashley, 1999; Ballard, 2000; Goldratt, 1997; Tommelein, 1998).

Traditional approaches to project management are mainly based on assumptions that do not consider the project complexity and its non-linear nature (Bertelsen, 2003). McCray et al (2002) states that poor systematic rules or heuristics to deal with the dynamic nature of projects lead to poor decisions.

In manufacturing, Work-in-Process (WIP) is the converse of a product or products at various stages of completion throughout the plant. It includes all the materials employed from the raw material after release for initial processing up to completely processed material awaiting final inspection and acceptance as a finished product (APICS, 1995). In construction, WIP can be related to the difference between cumulative progress of two consecutive and dependent activities. This difference characterizes the work units ahead of a crew, which can be employed to perform work. WIP can be designed as buffers to preclude the negative impacts of variability (e.g., idle time or wait time of crews, slow work, ineffective work, schedule delays), so it supports the Lean Construction principles.

V Gonzalez (2013) states that in construction, WIP can be understood as the difference between cumulative progress of two consecutive and dependent activities or processes, which characterises work units ahead of a crew that will perform work (Gonzalez et al, 2009). In repetitive building projects, for example, high-rise buildings, multi-storey buildings, and repetitive residential projects, WIP is more apparent as activities are performed in discrete repeated units. This methodology is part of a comprehensive buffer research that has been carried out during the last years by the authors (Gonzalez and Alarcon, 2009, 2010; Gonzalez et al, 2009, 2010, 2011).

D. Reliable Commitment Model

Reliable Commitment Model/Rational Commitment Model is an operational decision-making tool for predicting work progress in projects using statistical models. This model uses historical information of several construction variables such as labour, buffers and planned progress to attain a more reliable planning process at the operational level.

Vicente Gonzalez (2013) quotes that 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 labour 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.

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 Vicente Gonzalez (2013).

V. METHODOLOGY

A. Reliable Commitment Model Rcm

Reliable Commitment Model RCM is a new decision making tool based on lean principles. It uses statistical models to develop more reliable work plans at site or operational levels. RCM uses site information and planning reliable indicators. RCM helps in reducing variability as a means to reduce waste is the core of lean production philosophy. RCM increases planning reliability, reduces variability, and promotes continuous work flow with short waiting times. RCM analyses the problems of planning process at the operational level shows that one of the most important reason for non-completion of weekly plans in repetitive project is the lack of WIP. Main hypothesis of RCM is the process progress can be predicted by using variables such as labour, WIP buffer and planned progress, RCM uses multiple linear regression (MLR) to predict process progress at the operational level.

B. Multiple Linear Regression Model

RCM assumes typical MLR model of form:

$$y= \beta 0 + \beta 1x1 + \beta 2x2 \ldots \ldots . +\beta nxn +\in I \qquad (1)$$

Where,

Y – Dependent variable

Xi – Independent Variable

βi – Corresponding parameters of the dependent variable

ϵi – Random variables

The expression for predicting process progress in RCM is:

$$PRP = \beta 0 + \beta 1W + \beta 2WIPBf + \beta 3PP \qquad (2)$$

Where,

PRP – Predicted progress for a process (short term period)

W – No. of Workers for a process (short term period).

WIPBf – Available WIP buffer for a process at the beginning of short term period PP - Planned progress for a process

RCM collects the data from the historical data for each workweeks. The significant variables are selected in the models, since including redundant variables may lead to incorrect analysis of scenarios. The variable selection process uses the coefficient of determination, R2 and p value, leading to a trade-off between the number of variables, and the R2 and P-values. In general, MLR models with the least number of variables, and with the highest R2 and low P-values are preferred. The key heuristic is the maximization of the R2 value and minimization of the P-value

C. Process Reliability Index(PRI)

The prediction accuracy of RCM is evaluated by using two indicators. PRI measures the degree of process effectiveness from a commitment standpoint and it is expressed as:

$$PRIi,j = (APi,j) \times 100 \qquad (3)$$

Where,

PRIi,j is the process reliability index for week i and process j(%); i=1,2…n, j=1,2,..m

APi,j is the actual progress for week i and process j i=1,2…n, j=1,2,..m

PPi,j is the planned progress for week i and process j; i=1,2…n, j=1,2,..m

PRI values are limited between 0 and 100%. A low PRI means unreliable process planning and a PRI close to 100% means the opposite. From a lean production viewpoint, PRI also measures workflow variability. In construction, workflow is characterized by crews moving from one location to another and completing the work that is prerequisite for the following crew to start working (Tommelein et al. 1999). Thus, a low PRI indicates a highly variable workflow and unreliable execution of planned progress. In contrast, a high PRI represents a stable and predictable workflow and a reliable execution of planned progress.

D. Planned Commitment Confident Level (CCL)

Predicted/Planned CCL, on the other hand, is a measure of the planning prediction reliability for a process made by both decision makers (planned progress) and/or RCM (predicted progress) and it is expressed as follows

$$Predicted\ CCL_{i,j} = \left[1 - \frac{(Predicted\ PRI_{i,j} - Actual\ PRI_{i,j})}{Actual\ PRI_{i,j}}\right] \times 100 \quad (4)$$

$$Planned\ CCL_{i,j} = \left[1 - \frac{(Planned\ PRI_{i,j} - Actual\ PRI_{i,j})}{Actual\ PRI_{i,j}}\right] \times 100 \quad (5)$$

Where,

Predicted/Planned CCLi,j - CCL for week i and activity j (%) for both predicted and planned PRI.

Predicted CCLi,j- Predicted PRI for week i and activity j.

Planned CCLi,j -Planned PRI for week i and activity j, which is estimated by decision makers on the basis of their experience in a given planned progress. Although this value can be between 0% and 100%, planners usually aspire to a 100% Planned PRI.

Actual PRIi,j- Actual Process Reliability Index for week i and activity j. Predicted/Planned CCL measures the activity commitment accuracy for the predicted/planned PRI in relation to actual PRI. CCL does not measure confidence on the progress of activities. If Predicted/Planned PRI is less than Actual PRI, the Predicted/ Planned CCL are set to 0.

E. Research Methodology

The research methodology has three stages:
Stage 1: Selection / Creation of Activities
Stage 2: Multiple linear Regression (MLR)Models
Stage 3: RCM Planning Process

F. Stages Of Rcm Performed Weekly

The main stages of the RCM, which are performed weekly, are the following:

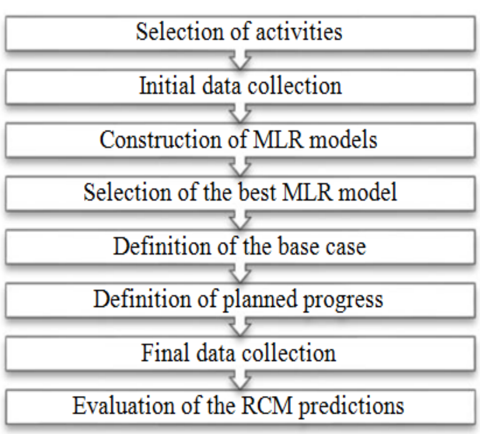

Fig. 1 RCM methodology

Selection of activities: A set of activities are to be selected by managers in order to improve their planning reliability. From a look ahead planning window the activities can be selected based on different project priorities and requirements.

Initial data collection: weekly production data are gathered for each activity. At the beginning of each week project managers estimate PP, planned PRI, and planned W, and measure the WIPBf size, which are required to predict. At the end of the week, AP and actual W are measured.

Construct the MLR models: Next step in the RCM model is to develop the MR models using SPSS with the data collected

Selection of the best MLR model: After 2 weeks, the available data can be used to start the statistical analyses to define the best MLR model. To construct a MLR model, AP, PP, WIPBf sizes, and actual W are used.

Base case: The base case is determined by applying the RCM and its nomograph to the initial data. The production frame PP, planned W, and. WIPBf is kept for the predicted PRI, if it satisfies preferences.

Modify production frame using trial and error: Usually actions should be performed to try to improve predicted PRI to make it closer or equal to 100. A strategy could be to increase the W levels to achieve higher predicted PRI values. Another strategy could be to decrease PP.A third strategy, increasing the WIPBf size increases the PP level. Finally, project managers select a predicted PRI value and a production frame according to their preferences, taking into account labour cost for a higher W level, and time to produce a higher WIPBf size, among others.

Definition of the planned progress: By using production frame Stage 7, a planned progress is estimated at the beginning of each week. Decisions can be taken to either use the RCM prediction as planned progress or keep their own estimate. Gradually should tend to use the RCM estimate.

Final data collection: The final data are gathered at the end of each week, which is necessary for further RCM predictions. The data measured are AP and actual W.

Evaluation of the RCM predictions: Once a labour week has finished, the main accuracy measures for the RCM prediction are computed, that is, predicted and actual PRI and predicted and planned CCL. This is a key stage to evaluate the quality of RCM predictions. Finally, the RCM process is repeated in Stage 11 similar to Stage 2 without AP and actual W information and Stage 12 similar to Stage 3 without intermediate decisions until the activity has been completely executed.

G. Reliable Commitment Model Framework

To study the impact on project performance of the methodology a repetitive building project is considered. Set of activities was analysed during 20 weeks in the project. Table 4.2 shows the main production parameters defined in the MLR models.

These 20 weeks comprises of three periods which are distinguished as:

1. The no-predictions period (weeks 1–2), in which data is collected as input for the RCM;
2. The predictions/ no-decisions period (weeks 3–16), in which planning predictions were performed to show the RCM capabilities but were not used to make decisions; and□
3. The predictions/ decisions period (weeks 17–20), in which the RCM outputs are considered to make planning decisions.

VI. RESULTS AND DISCUSSIONS

A. Multiple Linear Regression Model

In this stage, select activities to improve their planning reliability. Thus, activities are created within SPSS to get the statistical parameters by multiple linear regression (MLR) model.

The expression for predicting process progress in RCM is:

$$PRP = \beta_0 + \beta_1 W + \beta_2 WIPBf + \beta_3 PP \qquad (6)$$

Where,

PRP – Predicted progress for a process (short term period)

W – No. of Workers for a process (short term period).

WIPBf – Available WIP buffer for a process at the beginning of short term period

PP - Planned progress for a process

MLR models are being developed after the first two weeks and the parameters in the above Eq. 6.1 is obtained. Following table 6.1 shows the obtained result of first MLR model created in SPSS

TABLE II VARIABLES ENTERED/REMOVED IN SPSS

Model	Variables Entered	Variables Removed	Method
1	WIP_BF[a]		Enter

a. Tolerance = .000 limits reached

b. Dependent Variable: PP

TABLE III B R^2 VALUE IN SPSS

c.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.976[a]	0.96	-	-

a. Predictors: (Constant), WIP_BF

TABLE IV COEFFICIENTS OBTAINED IN SPSS

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
1	(Constant)	716.667	.000	-
	WIP_BF	.222	.000	1.000

Dependent Variable: PP

Thus the obtained results helps to arrive at a MLR model with equation as follows:

$$PRP = 716.667 + 0.222WIPBf \qquad (7)$$

Similarly MLR models for every week is obtained in SPSS as follows:

TABLE V MLR MODEL EQUATIONS

Week	MLR Model Equation
Week 3	PRP = 716.667 + 0W + 0.222WIPBf + 0PP
Week 4	PRP = 994.775 + 0W − 0.172WIPBf − 0.225PP
Week 5	PRP = 991.024 + 0.019W − 0.17WIPBf − 0.226PP
Week 6	PRP = 991.712 + 0.016W − 0.17WIPBf − 0.226PP
Week 7	PRP = 991.746 + 0.017W − 0.17WIPBf − 0.226PP
Week 8	PRP = 992.007 + 0.017W − 0.171WIPBf − 0.226PP
Week 9	PRP = 991.943 + 0.015W − 0.171WIPBf − 0.225PP
Week 10	PRP = 991.904 + 0.015W − 0.171WIPBf − 0.225PP
Week 11	PRP = 991.848 + 0.016W − 0.171WIPBf − 0.225PP
Week 12	PRP = 991.535 + 0.017W − 0.171WIPBf − 0.225PP
Week 13	PRP = 991.660 + 0.017W − 0.171WIPBf − 0.225PP
Week 14	PRP = 1005.781 + 0.011W − 0.187WIPBf − 0.22PP
Week 15	PRP = 1006.101 + 0.010W − 0.187WIPBf − 0.22PP
Week 16	PRP = 1009.793 + 0W − 0.192WIPBf − 0.216PP

The next stage is to make predictions for the predictions/ decisions period (weeks 17–20), in which the RCM outputs are considered to make planning decisions.

TABLE VI OUTPUTS FOR THE PREDICTIONS/ DECISIONS PERIOD (WEEKS 1–16)

Week	W	WIP_Bf	PP	PRP	AP	Pr_PRI	A_PRI	Pr_CCL	R^2	Variables Selected
1	204	1500	1050		550		52.38			
2	198	1050	950		600		63.16			
3	197	1250	1500	441.67	400	29.44	26.67	89.58	0.96	WIP_BF
4	142	1000	1200	552.78	450	46.06	37.5	77.16	0.69	WIP_BF,
5	206	1200	1350	485.84	400	35.99	29.63	78.54	0.78	WIP_BF, W
6	185	1000	1100	576.07	455	52.37	41.36	73.39	0.75	WIP_BF, W
7	170	950	1100	584.54	500	53.14	45.45	83.09	0.92	WIP_BF, W
8	197	1000	950	609.66	450	64.17	47.37	64.52	0.64	WIP_BF, W
9	219	950	1050	596.53	550	56.81	52.38	91.54	0.98	WIP_BF, W
10	217	900	1400	526.26	450	37.59	32.14	83.05	0.97	WIP_BF, W
11	237	1200	1000	565.44	500	56.54	50	86.91	0.97	WIP_BF, W
12	209	1000	900	621.59	550	69.07	61.11	86.98	0.97	WIP_BF, W
13	200	900	1200	601.76	580	50.15	48.33	96.25	0.98	WIP_BF, W
14	189	1200	1045	553.56	500	52.97	47.85	89.29	0.93	WIP_BF, W
15	165	1000	1250	560.6	530	44.85	42.4	94.23	0.98	WIP_BF, W
16	134	900	1000	620.99	450	62.1	45	62	0.8	WIP_BF, W

During this period the process reliability index is considered to be 100%.
Table VII shows the outputs for the predictions/ decisions period (weeks 17–20).

TABLE VII PREDICTIONS/ DECISIONS PERIOD (WEEKS 17–20)

Week	W	WIP_Bf	PP	PRP	AP	Pr_PRI	A_PRI	Pr_CCL	R2	Variables Selected
17	167	1300.00	1050.00	533.36	450.00	50.80	42.86	81.48	0.96	WIP_BF, W
18	189	1000.00	600.00	677.00	650.00	100.00	100.00	100.00	0.98	WIP_BF, W
19	171	950.00	650.00	686.96	680.00	100.00	100.00	100.00	0.98	WIP_BF, W
20	198	850.00	688.00	705.33	700.00	100.00	100.00	100.00	0.98	WIP_BF, W

The PRP variations is obtained as follows:

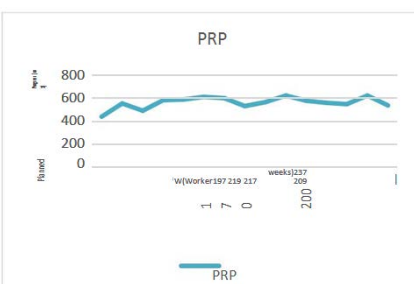

Fig. 2 Predicted Progress for a Process

RCM application evolution found in the Planned Progress (PP), Actual Progress (AP) and Predicted Progress for a Process (PRP) during the considered worker Weeks (W) are shown in the following figures fig. 6.2 -6.6.

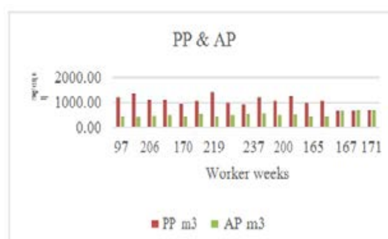

Fig. 3 PP & AP vs. W

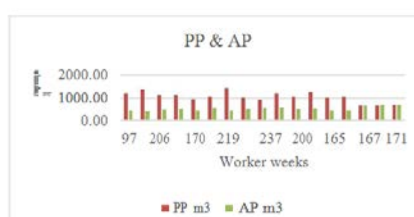

Fig. 4 PP & AP vs. W

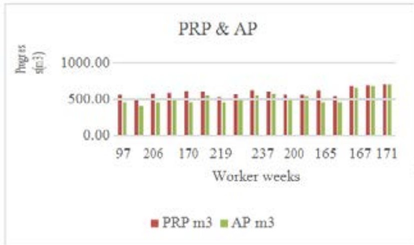

Fig. 5 PRP & AP vs. W

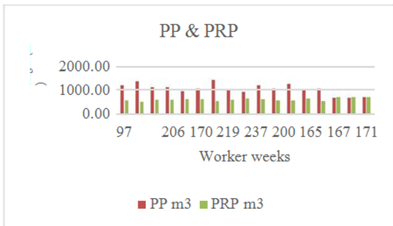

Fig. 6 PRP & PP vs. W

Above graphical representations clearly shows that the last three weeks, i.e. predictions/decisions week were the RCM decisions were taken have better planning and actual progress is nearly similar to predicted progress of the process.As mentioned previously, the RCM prediction started on week 18. The objective of this research was to study the RCM-based WIP buffer management methodology in a real case to determine its potential impacts. A detailed analysis of Weeks 18–20 is discussed next. During the 18th week, activity improved its actual progress in relation to planned progress, 650 and 600m^3, respectively, but it was lower than the predicted progress, 650 versus 677m^3. The actual level of W was lower than the planned W: 200 and189 worker weeks, respectively. Despite this, it achieved a reasonable level of actual progress and an actual PRI of 100% due to the increased labour productivity.

During the 19th week, activity increased its actual progress compared with the planned progress, 680 and 650m^3, respectively, and it had a higher progress than predicted, 680 versus 686.96m^3. This resulted in a higher actual level of W than the planned level, 171 and 185 worker weeks, respectively. This week made better use of the increased labour resource and achieved a higher PRI levels (100%).

During the 20th week, activity improved its actual progress compared with the planned progress, 700 and 688m^3, respectively. It also had a higher progress than predicted, 700 versus 705.33m^3, in which W was kept constant at 198 worker weeks for both planned and actual. When W is constant, an increased WIP buffer size promotes the best use of labour resources and the highest PRI level

VII. CONCLUSION

RCM can provide a practical approach to manage buffer in construction projects at the operational level. It can also help to promote adopting a more rigorous approach in the buffer management culture in construction. 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. 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. In this research the prediction/decisions period (week 17- shows much more reliable and accurate prediction of progress of the process considered. The predictions are done considering the Process Reliability Index as 100%. The strategies that could be adopted to modify the production frame is to decrease the Planned Progress or increase the WIPBf size or manage the Worker weeks accordingly. Above strategies allows to predict the future progress with higher reliability and accuracy. This predictions helps project managers to plan better on the basis of a statistical and mathematical model other than using historical data and intuitions of the project managers based on experience.

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