USE OF A RISK MATRIX AS SELECTOR OF ACTIVITY PRIORITY EXECUTION BASED ON PROJECT HISTORY

Diego Cisterna[1], Luis Fernando Alarcón[2] and Isabel Alarcón[3]

ABSTRACT

This paper proposes a set of algorithms that use Last Planner System® (LPS) metrics, obtained from a software that manage LPS data, and some heuristics to build a Risk Matrix which organizes activities in order of importance. The calculations made by these algorithms are fed by historical project information. The activity importance is determined by the level of impact. This level is defined combining criticality and probability levels that are calculated through the analysis of selected variables: numbers of links between activities, assignment of resources, constraint release history, reasons for noncompletion, percent plan complete (PPC), etc.

Identification and prioritization of activities which have a high impact on a project is a useful way to reduce variability, preventing the triggering of chains of delays. Along with this, the mere fact of establishing the most significant activities in front of all participants of planning meetings, generate a psychological effect on all those responsible for tasks, which should align efforts accordingly. This tool is consistent with the LPS philosophy; it takes the team members behavioral history and includes it in the algorithm, producing a warning that indicates that an activity must be followed closely, without assigning responsibility to any team member.

KEYWORDS

Risk assessment matrix, Last Planner System, variability, Lean Construction, constraint analysis.

INTRODUCTION

Variability is a big enemy of successful project management. One way to measure variability in plan execution is PPC (Ballard, 2000), an indicator proposed in the LPS. Regrettably, many issues of different nature affect project execution, causing the completion of all scheduled activities to be difficult to reach. Theoretically, we have to control all activities involved in short-term periods, but the resources are not always enough to do this. In order to make best use of limited resources it is important to understand what activities should have priority in a project schedule.

This paper report on the challenge of creating a new indicator that could help to sort activities by importance based on historical collected data. To develop this

1 Research Assistant, GEPUC, Engineering Student, Escuela de Ingeniería, Universidad de Chile, E-Mail: dicister@ing.uchile.cl

2 Professor of Civil Engineering, Escuela de Ingeniería, Universidad Católica de Chile, Casilla 306, Correo 22,Santiago, Chile, E-Mail: lalarcon@ing.puc.cl

3 Investigation and Development Manager, GEPUC (www.gepuc.cl), Santiago, Chile, E-Mail: ialarcon@gepuc.cl

indicator, the authors had access to data provided by specialized software used to support LPS, and used heuristics, validated by a team of experienced LPS users.

The first idea analyzed was the development of an Activity Criticality Rate, which could generate a list of weekly activities sorted by high to low relevance to better understand which activities must be priority. Assuming that keeping a 100% PPC for each short term period during the whole project is an almost utopian goal, it is of vital importance the knowledge of which activities are those that must concentrate every effort to complete. Observing the inputs of the LPS, the construction of this indicator for each activity can be done considering the following data: number of links with other activities, duration of the activity and assigned resources to the activity. However, there are other aspect to consider: in a project there are activities that can slightly delay the work, or that have few resources assigned to them, but nevertheless are recurrent in time, there are other activities that can create significant delays as well or have many resources assigned to them, but the probability of failure to complete them is minimal. *¿Which type of activity is more relevant?*

To solve this dilemma, it's necessary to introduce a second dimension to the activity relevance analysis: The Noncompletion Probability. This new dimension encourages the use of a new project control tool called Risk Matrix (see Table 1) which in time introduces a new concept for the classification of activities according to their relevance: Impact. This new classification concept is no more than a consideration of different combinations between probability and criticality which allow the sorting of activities according to these two dimensions on many levels.

The PPC records, the Reasons for Noncompletion (Ballard 2000), the Constraints Release records related to the activity, as well as the Reliability of the Constraints Release process, in case the activity involves release of constraints, may be used to estimate a level of Activity Noncompletion Probability which together with the Criticality level is used to define the Impact level of the activity that will finally allow a relevance sorting.

Table 1: Risk Matrix

		ACTIVITY NONCOMPLETION PROBABILITY				
		Rare	**Improbable**	**Possible**	**Probable**	**Almost Certain**
CRITICALITY	**Catastrophic**	M	H	E	E	E
	High	M	H	H	E	E
	Moderate	L	M	H	H	E
	Low	L	L	M	H	H
	Insignificant	L	L	L	M	M

IMPACT	L = Low	M = Medium	H = High	E = Extreme

The Risk Matrix is not a new tool, in fact, there are planning and control project softwares that use this instrument within their other indicators. Wambeke et al (2012) in a recent publication proposed the study of a Risk Assessment Matrix combined with the LPS methodology to reduce variation in mechanical related construction tasks. The use of the Risk Assessment Matrix proposed in this paper differs from previous studies mainly in the way this indicator is developed for each activity which is supported by the data provided by software that supports LPS implementation.

While in previous studies the matrix is used mainly as a visual aid for the identification or communication of the activity's impact level on the project, in which the choice of criticality and probability is made by the project's administrator relying on experience, in the Risk Matrix proposed in this paper, the impact level is calculated automatically through algorithms that use project historical information.In relation to the impact that the inclusion of this Risk Matrix would have on projects that use LPS, a positive improvement in variability control stands out (Wambeke et al, 2012). The identification of high impact activities allows the assignation of higher efforts in the completion of those that could trigger a chain of delays in the future.

Along with this, in the planning meeting, the mere fact of identifying and naming the higher impact activities in front of all participants generates a great effect at a psychological level on those responsible for the task. They would show more concern in the effective accomplishment of said critical activity, which should allow a fluid progress in the project. The Risk Matrix is used in a way which is consistent with the LPS methodology, it does not directly accuse a Last Planner; instead it takes the behavioral background and implicitly enters it in an algorithm alerting that some of the activities must be closely followed without directly accusing the person responsible that triggered the warning. For instance, if an activity has constraints that must be released by foreman X and foreman X has a record of low reliability in this process, thereby the activity will have a high no completion risk. However the Risk Matrix is not only fed by this variable, but also by the Reasons for Noncompletion and Constraints Release Records and PPC Records by probability and Critical Path, Number of Links, Duration of the Activity and Activity Assigned Resources by criticality. In this way, the Risk Matrix provides an anonymous Impact result to the rest of the team, which will not depend directly on foreman X. Nonetheless the attention given to the activity will cause foremen X and everyone responsible in the activity completion to be more conscious on the associated constraint release process resulting in a positive effect for the project.

INDICATOR CHARACTERISTICS

Figure 1 may help to understand the structure of the proposed indicator. The Risk Matrix is made of two dimensions: Criticality and Probability. The first of these dimensions will be composed by indicators that will enable the quantification of the importance of each activity in comparison to others, while the second will seek to determine the probability that a particular activity is not completed.

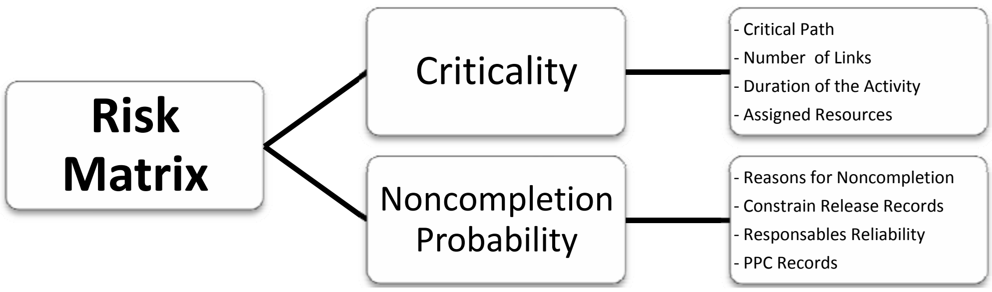

Figure 1: Risk Matrix Construction Diagram

Both dimensions will be created as sub-indicators articulated by algorithms that use the indicators enlisted in the Figure 1 as normalized variables that assign a level of criticality and probability within a total of five levels for each dimension (Table 2).

The combination of the levels of these two dimensions will determine the final impact level of the activity, classified in four levels shown in Table 3.

The Risk Matrix shown on Table 1 shows distributed proposed distribution according to their combination.

Table 2: Risk Matrix Sub-Indicators (dimensions) Levels

Criticality	Noncompletion Probability
Catastrophic	Almost Certain
High	Probable
Moderate	Possible
Low	Improbable
Insignificant	Rare

Table 3: Activity Impact Level on the Risk Matrix

Impact	Number of Combinations Assigned in Table 1
Low	6
Medium	6
High	7
Extreme	6

CONSTRUCTION OF THE INDICATOR

This section describes the proposed method to obtain the Criticality Indicator as well as the Probability Indicator which combined form the Risk Matrix that is featured in this paper. The reasons for choosing these indicators are discussed in Cisterna (2013).

CREATION OF THE CRITICALITY SUB-INDICATOR

Mathematical Model for the Criticality Sub-Indicator

The criticality of the activities will be determined by an algorithm that will take each of the previously listed variables, will normalize them so as to be able to compare them in the same scale and later will introduce a calibration coefficient so that each variable will have a different "weight" within the formula.

More specifically, the Criticality sub-indicator will be composed by the following mathematical expression:

$$Cr_i = k_1 \cdot NL_i + k_2 \cdot DA_i + k_3 \cdot AR_i + k_4 \cdot CP_i^{0,1}$$

Where:

Cr_i: Activity i' sub-indicator's criticality.

NL_i, DA_i, AR_i, $CP_i^{0,1}$: Main variables of the sub-indicator. Explained below.

k_1, k_2, k_3, k_4: Calibration coefficients in the model.

Criticality Sub-Indicator Variable Normalization

The fact that every variable that feeds this Sub-Indicator is quantified in different units of measure, justifies the need of introducing a system which normalizes them to a common scale. The methodology for this will be the development of a particular qualification system for each variable, which will assign a value from 0 to 1 according to the state of each one of them.

The NL_i, DA_i, and AR_i variables will be based in a calibration system using the "Percentile Ranking" statistical tool detailed in the following lines, while the $CP_i^{0,1}$ variable will be defined as a binary value due to the excluding nature of the state of the variable.

The "Percentile Ranking" is a mathematical function that gives the ranking of a value from a group of data like a percentage of the same group (0 to 1, inclusive). This function is used to evaluate the relative position of a value within a group. It is the reverse measure of the "Percentile" of the group of data. The Percentile Ranking mathematical function is defined as:

$$PR_i = \frac{f_{ac,i-1}}{n}$$

Where:

PR_i : Percentile ranking of a determined i value.

$f_{ac,\,i-1}$: Cumulative frequency of the element previous to the i value.

n : Total number of elements in the group of data.

Because the mathematical expression uses the cumulative frequency of the data, it is necessary that they are in ascending order before applying the analysis.

Number of Links (NL_i): Using "Percentile Ranking", the qualification given to each activity in relation to the Number of Links that they have associated will be defined as:

$$NL_i = \frac{fNL_{ac,i-1}}{TA}$$

Where:

NL_i : Qualification given according to the Number of Links of activity i.

$fNL_{ac,\,i-1}$: Cumulative frequency of the Number of Links of the activity previous to activity i.

TA : Total number of activities in the project.

Duration of the Activity (DA_i): Using "Percentile Ranking", the qualification given to each activity in relation to the duration of it (measured in days), will be defined as:

$$DA_i = \frac{fDA_{ac,i-1}}{TA}$$

Where:

DAi : Qualification given according to the Duration of the Activity i.

$fDA_{ac,\,i-1}$: Cumulative frequency of the Duration of the Activity previous to activity i.

TA : Total number of activities in the project.

Assigned Resources (AR_i): Using "Percentile Ranking", the qualification given to each activity in relation to the resources assigned to it (measured in monetary value or in MH), will be defined as:

$$AR_i = \frac{fAR_{ac,i-1}}{TA}$$

Where:

ARi : Qualification given according to the Assigned Resources to activity i.

$fAR_{ac,\,i-1}$: Cumulative frequency of the amount of resources of the activity previous to activity i.

TA : Total number of activities in the project.

Critical Path ($CP_i^{0,1}$): This is a binary indicator; it doesn't leave space for values in between in the scale from 0 to 1, because it defines if an activity is or not in the project's critical path. Mathematically it's defined as:

$$CP_i^{0,1} = \begin{cases} 1 & \rightarrow If\ activity\ i\ belongs\ in\ the\ Critical\ Path. \\ 0 & \rightarrow If\ activity\ i\ doesn't\ belong\ in\ the\ Critical\ Path. \end{cases}$$

Where:

$CP^{0,1}$: Qualification given binary (0 or 1) according to the presence of activity i in the project's Critical Path.

Calibration of the Criticality Sub-Indicator's Mathematical Model

All considerations made above, not always be produced as estimated, for example, linkages may exist between activities with enough gaps in time to avoid delay transference from the previous task; it can also happen that the duration of the activity is not directly proportional to the amount of incidents that may happen. All these anomalies will be attempted to be controlled with the use of calibration coefficients within the algorithm in which all this indicators will be used.

These calibration coefficients will be defined from the results of a poll made by the GEPUC[4] professionals in which each one, based on their experience in different types of projects, assigns a value to each coefficient. The average of these answers is shown in Table 4 and will be the multipliers defined for this first indicator calibration.

Table 4: Criticality Sub-Indicator Calibration Coefficients

Coefficient	K1	K2	K3	K4
Value	0,26	0,168	0,211	0,361

Creation of the Probability Sub-Indicator Mathematical Model

The Noncompletion Probability sub-indicator will be made in the same way as above indicator. The mathematical expression of this is the following:

$$Pr_i = k_1 \cdot RNC_i + k_2 \cdot RR_i + k_3 \cdot \overline{RCR_k} + k_4 \cdot \overline{PPC_k}$$

Where:

Pr_i : Noncompletion Probability sub-indicator of the i activity.

$\overline{RNC_i}$, RR_i, RCR_k, $\overline{PPC_k}$: Main variables of the sub-indicator. Explained below.

k_1, k_2, k_3, k_4: Calibration coefficients for the model.

Variable Normalization for the Probability Sub-Indicator

Due to the fact that all the variables used to articulate this sub-indicator are measured in percentages, the qualification of these will be obtained via direct conversion scale 0-100% to the 0-1 scale, having in some cases to subtract to 100% the percentage of the variable in study so as to determine the qualification in cases that the relation in proportionally inverse.

Reasons for Noncompletion (RNC_i): Because the records of the different causes are calculated through the recurrence percentage with which these appear according to the function, the qualification will be directly the percentage of said function. This

[4] GEPUC: Center for Excellence in Production Management of "Pontificia Universidad Católica de Chile". Consulting Firm that for over 10 years has led the implementation of Lean Management and its derived tools in Chilean companies associated to the sectors of construction, engineering, mining, and health.

is based on the fact that the link is directly proportional; the higher function accumulated RNC percentage, the higher the activity Noncompletion Probability is.

This way, the variable is mathematically defined as:

$$RNC_i = \frac{PCR_i}{100}$$

Where:

RNC_i : Qualification given according to the function contribution to registered Reasons for Noncompletion associated to activity i.

RCR_i : Percentage of Contribution to Reason for Noncompletion associated to activity i.

Reliability of the Responsible (RR_i): Because this variable measures the reliability percentages, the given value will be proportionally inverse to the Noncompletion Probability: low reliability, means high activity Noncompletion Probability. Considering this, it's necessary to subtract the registered value to 100% to thus obtain the "mistrust of the responsible" that will be directly proportional to the Noncompletion Probability. Said percentage value transformed to 0 to 1 scale will be the value qualification. The defining mathematical expression is as follows:

$$RR_i = \frac{100 - PRR_i}{100}$$

Where:

RR_i : Qualification given according to Reliability of the Responsible in constrain release percentage associated with activity i.

PRR : Percentage of Reliability of the Responsible in constrains release percentage associated to activity i.

Restriction Liberation Evolution: Just like in the previous case, this variable is proportionally inverse to the activity Noncompletion Probability for which it's necessary to subtract its value for each period of time to 100% and after calculate the "non liberation restriction" percentage average from the last period from the lookahead in record. The mathematical expression is as follows:

$$\overline{RCR_k} = \frac{\sum_{j=k-(n-1)}^{k}(100 - PCR_j)}{n \cdot 100}$$

Where:

$\overline{RCR_k}$: Qualification given according to the historic Record of Constrains Release evolution average from the last Lookahead starting from the number k short period of time.

PCR_j : Percentage of constrains release from the number j short term period of time.

n : Number of short term periods of time contained in the previous Lookahead period.

Plan Completion Percentage: This case is the same as the last one, because it also involves a proportionally inverse to the activity Noncompletion Probability variable that must be averaged in the last registered lookahead period. Thus, the mathematical expression is articulated in the same way as the previous case.

$$\overline{PPC_k} = \frac{\sum_{j=k-(n-1)}^{k}(100 - PPC_j)}{n \cdot 100}$$

Where:

$\overline{PPCk}$: Qualification given according to the historic plan completion percentage average from the last Lookahead starting from the number k short period of time.

PPC_j : Percentage of plan completion from the number j short term period of time.

n : Number of short term periods of time contained in the previous Lookahead period.

Calibration of the Probability Sub-Indicator's Mathematical Model

All the consideration previously proposed may not always be as estimated, for example, it may be that the PPC behavior analysis doesn't give a reliable estimation of the activity completion probability due to the fact that it is strongly linked to the amount of activities that are committed in each period of time (there will always be high PPC values when few activities are committed).

The probability sub-indicator's calibration coefficients will be defined by the average of the poll answers of the GEPUC professionals. The results are presented on Table 5.

Table 5: Probability Sub-Indicator Calibration Coefficients

Coefficient	K1	K2	K3	K4
Value	0,219	0,375	0,206	0,2

Risk Matrix Calibration

After obtaining the calibration values and grade for each variable, the next step of the algorithm is to assign a level of Criticality and of Noncompletion Probability to each activity.

Since both the qualification system as calibration coefficients deliver values between 0 and 1, and also considering that the sum of the four calibration coefficients is 1, the value of the multiplication and the subsequent summation of all these elements will always remain within the same range. Since in a previous section are defined five levels for Criticality and Probability (see Table 2), simply divide the interval 0-1 in five sub-intervals and assign each a level corresponding to its magnitude. The designation of these sub-levels according to the interval that is each sub-indicator is shown in the following Table 6.

Table 6: Assignment Intervals of Criticality and Noncompletion Probability

Criticality	Noncompletion Probability	Level Assignment Interval
Catastrophic	Almost Certain	[0,8 – 1]
High	Probable	[0,2 – 0,8 [
Moderate	Possible	[0,4 – 0,6 [
Low	Improbable	[0,2 – 0,4 [
Insignificant	Rare	[0 – 0,2 [

Once the levels of Criticality and Noncompletion Probability are collected, the final step of the algorithm is to assign a level of Impact to the activity based on Table 1.

A computational simulation with random qualifications between 0 and 1 for approximately 1300 dummy activities is shown in the investigation made by Cisterna (2013) in order to observe the behavior of the Risk Matrix in action.

COMMENTS AND CONCLUSIONS

CRITICALITY INDEX

Because most of the variables that feed this sub-indicator account units (number of Links, number of duration days and amount of assigned resources), it was necessary to use a statistical tool to order the data according a ranking given by the range of them. Because that, the qualification system use the “Percentile Ranking” of each variable with which a percentage can be directly obtained (value from 0 to 1), depending on the total data group with which the particular value was being compared to. The main advantage of this measuring method is that it will assign higher values with higher amounts of units, but this magnitude with directly depend on how rare this value is within the data group. The practical effect of this phenomenon is perfectly adjusted to what is to be achieved by creating a criticality indicator: giving more importance only to activities that have characteristics relevant next to the group of activities in the project. If many activities have high values, it’s correct in this case to not give importance to said activities, because the indicator would be triggered by a “normal” characteristic in the project.

Summing up, using the “Percentile Ranking” function it can be achieved that the variables of the Criticality Sub-Indicator take relevance only when isolated high values exist; in other words, it makes the activities call attention not only for value magnitude, but also rarity within the group of activities in the project.

PROBABILITY INDEX

Creating a qualification system for this sub-indicator’s variables was simpler than for the Criticality sub-indicator due to the fact that all its variables gave results in the form of percentages, for which it was only necessary to use said percentages in small calculations to obtain the qualifications of each variable.

In the case of the Restriction Liberation State and Plan Completion Percentage averages; at first it had been proposed as all the historic registered values throughout the project average, however this was redefined as the average of the values obtained in the last Lookahead period, when considering the great mutation capacity that projects may have depending on the state in which they are, for this reason it would be counterproductive to punish high Noncompletion Probability activities based on the project’s performance many periods of time past. In other words, for the goal that is sought with this indicator, it is more convenient to use the project’s more immediate historic records.

RISK MATRIX

Calibrating the expressions that quantify the probability and criticality sub-indicator’s entered variables make the created indicator highly flexible to future modification and improvement. It’s enough to just modify the calibration coefficients to thus generate different answers for the indicator in case that it’s behavior would want to be improved based on another type of study besides the one made for the occasion that was based on the experience of GEPUC professionals. Similarly, the Level Assignment Interval can be changed (see Table 6) in order to manipulate the amount of activities with a kind of impact is wanted to have.

WORK CONTINUATION PROPOSAL

Besides the recalibration of the Sub-Indicators and the Level Assignment Interval through the implementation of the indicator in real projects, it's proposed as future work the realization of a real time follow up of two projects, one with the Risk Matrix and the other without it and compare the participant's behaviors in meetings, taking record of the instantaneous reactions when finding out the critical activities and their behavior after the short time period of time, testifying if in fact more critical tasks are completed when identifying them.

It is also proposed to take record of the amount of critical tasks using the Risk Matrix in both projects week by week (or in the respective short term period of time), but only giving the participants a list of critical tasks in the meetings of one of the projects. This so as to after compare the percentage of the critical tasks completed in the project in which the participants had knowledge of the critical tasks, versus the percentage of critical tasks completed in the project in which the participants completed them randomly or by own criteria due to the lack of knowledge in the task's order of relevance.

Finally take record and compare the variability in the progress of both projects from beginning to end effectively probing if the Risk Matrix generates a substantial improvement in the progress of the project in which it was implemented.

REFERENCES

Alarcón, L (2008). **“**Guía para la implementación del sistema del último planificador”, GEPUC, Pontificia Universidad Católica de Chile, Santiago, Chile.

Ballard, G. (2000). “The Last Planner System of Production Control”. Ph.D. Thesis, Civil Engineering, University of Birmingham, Birmingham, United Kingdom.

Campero, A. and Alarcón, L. (2003). “Administración de Proyectos Civiles”, Universidad Católica de Chile, segunda edición, Chile.

Cisterna, D. (2013). “Desarrollo y Evaluación de Indicadores de Control para Implementación en Software de Planificación y Control de Proyectos Basado en Metodología Last Planner”, Memoria para optar al Título de Ingeniero Civil, Universidad de Chile, Chile.

DEMRE. (2008). “Nociones básicas de estadística utilizadas en educación”, Universidad de Chile, Departamento de evaluación, medición y registro educacional, Chile.

Kelley, James. (1961). “Critical Path Planning and Scheduling: Mathematical Basis”. Operations Research, Vol. 9, No. 3, May–June, 1961.

Project Management Institute. (2004). “A Guide to the Project Management Body of Knowledge Edition” *(PMBOK® Guide)*, 2004 Edition

Sabbatino, D. (2011). “Directrices y recomendaciones para una buena implementación del sistema Last Planner en proyectos de edificación en Chile”, Memoria para optar al Título de Ingeniero Civil, Universidad de Chile, Chile.

Serpell, A. Alarcón, L. (2007). “Planificación y control de proyectos”, Universidad Católica de Chile, segunda edición, Chile.

Wambeke, B., Liu, M., and Hsiang, S. (2012). “Using Last Planner and a Risk Assessment Matrix to Reduce Variation in Mechanical Related Construction Tasks.” *J. Constr. Eng. Manage.*, 138(4), 491–498.