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UNVEILING THE HIDDEN HIGH VARIABILITY IN PROCESSES WITH STABLE AND GOOD PPC RESULTS

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ABSTRACT

Despite high and stable Percentage of Plan Completed (PPC) values obtained in projects where Last Planner® System (LPS) was implemented, construction processes often conceal variability, undermining true completion. Likewise, LPS metrics rely on a deterministic approach for measuring the performance of processes without contrasting them with non-deterministic variables, which can provide a new perspective and new room for improvement. This is why, this paper introduces four new metrics – Percentage of Plan Completed+ (PPC+), Percentage of Plan Completed++ (PPC++), Percentage of Plan Completed+ based on random scheme (PPC+r), Rate of Waste (Rw), and Rate of Planning Assessment (Rpa) – to unveil hidden variability around activity daily schedule, rework, excess capacity, and planning. Further, utilizing statistical modeling to define the pioneering stochastic indicator Rpa, the study presents an important leap from traditional LPS deterministic metrics. Thus, by also conducting one survey among LPS practitioners on PPC conception and usage, it illuminates how seemingly stable estimated PPC values can misrepresent process performance.

These metrics offer a transparent brand-new assessment way, revealing new opportunities for improvement aligned with lean principles. The study also provides foundation and directions for further research on hidden variability which can propel the current LPS approach.

KEYWORDS

Lean construction, Last Planner® System, PPC, metrics, stochastic indicator.

INTRODUCTION

This approach introduces a novel method for evaluating hidden variability within the context of the variability research field on PPC results, addressing existing gaps in this field. This becomes apparent when the study quantitatively shows that even when a process maintains a consistent PPC of 100%, variability may persist unnoticed.

The newly introduced PPC+ and PPC++ metrics scrutinize daily fluctuations within weekly PPC assessments, revealing variability in activity leaps and its impact on deliverable completion, respectively. Completion, within this framework, pertains to fulfilling technical requirements, distinguishing it from mere quantity or activity execution. Similarly, Rw highlights the waste of hidden resources employed to address unnoticed variability.

Moreover, taking note that randomness can be explained as out of control variability (Hamzeh, 2009), and adhering to the principle that planned results are diametrically opposed to random outcomes, and the closer planned results align with random outcomes, the poorer the planning execution, Rpa serves as a stochastic indicator utilizing a random variable (PPC+r)

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obtained by estimating the most probable PPC+ value within a random scheme for a particular process model. For defining this, the author conducted a simulation with a constant 100% PPC while varying PPC+ values.

The author doesn't assume that the basis of LPS approach takes completion as independent of meeting technical requirements. However, he asserts that there are signs that in Peru LPS practitioners understand PPC as an outcome of finalized activities, assuming that these activities result in deliverables meeting the technical requirements. As a result of this assumption, there could be a distortion in the PPC, as certain packages assumed to be finished may still require additional work subsequently. As LPS does not explicitly include formal procedures for quality control, relying on existing quality management systems to ensure the quality of completed work packages (Ibarra et al., 2022), there is a need to define indicators aligned with the LPS approach regarding completion.

TERMINOLOGY

Completion

The project scope's completion is assessed in accordance with the project management plan, whereas the product scope's fulfillment is evaluated based on the product requirements (PMI, 2017). In this paper, completion is accomplished only when deliverables meet technical specification, and since defects are not part of the specifications, completion also means free of defects.

Deliverable

Any unique and verifiable product, capability or result to perform a service that is required to be produced to complete a process, phase, or project (PMI, 2017).

Requirement

The term *requirement* is defined as a capability or condition that is required to be present in a product, service, or result to satisfy an agreement or other formally imposed specification (PMI, 2017).

PURPOSE

The aim of this study is to propose new metrics PPC+, PPC++, PPC+r, Rpa, and Rw, which collectively unveil hidden variability in regular high-performance and low-variability PPC results. Likewise, this paper presents Rpa as a pioneering stochastic indicator for LPS approach, opening the door for further indicators of this kind.

METHODOLOGY

Observation and Hypothesis

Describe regular construction process characteristics, how they are understood and measured by LPS practitioners, and provide possible explanations.

Literature Review and Foundations

Conduct a comprehensive literature review on the LPS key metrics, establishing the theoretical foundations for new metrics, including the understanding of completion, deliverables, and requirements.

Assessment of PPC Understanding

Conduct a poll among LPS practitioners to explore their understanding on completion. Evaluate emerging insights to identify potential misconceptions to later assess the necessity of introducing supplementary metrics to address these misconceptions

New Metrics Definition

Define the PPC+, PPC++, PPC+r, Rpa, and Rw metrics in detail, explaining the rationale and formulas for each. Describe the underlying assumptions and constraints applied.

Simulation and Theoretical Results

Assess selected metrics through simulation modeling and analyze results to uncover hidden variability despite a consistent 100% PPC. Obtain statistical values for PPC+ in a random scheme, describe its theoretical relation with Rpa.

Site Research Project

Propose starting points, procedural steps, and recommendations for conducting on-site research to validate the theoretical findings.

Conclusions

Synthesize theoretical and practical findings on PPC understanding and completion. Assess new metrics' utility in uncovering hidden variability and improving PPC estimation.

OBSERVATION AND HYPOTHESIS

In Peru, LPS practitioners commonly evaluate variability by monitoring PPC and other LPS metrics' behaviour, relying on measured resultant data, which unveils a prevalent deterministic approach. While this practice illuminates processes and guides actions, inherent biases may prevent thorough examination of resultant data upstream, alongside to misconceptions about key definition of completion in terms of deliverables rather than solely activities.

LITERATURE REVIEW AND FOUNDATIONS

PPC stands as the predominant metric in LPS, typically associated with effective weekly work planning and successful LPS implementation. It serves as a *post-production* gauge of the reliability of weekly work planning (El Samad et al., 2017). Likewise, other well-known metrics are the now called Tasks Anticipated (TA) and Tasks Made Ready (TMR) (Ballard, 1997) which can be used to align the weekly work plan assignments with the lookahead plan. On the other hand, Planned Work Ready (PWR) is a metric used for assessing the quality of the lookahead process; this metric serves as a forecast and can provide a better evaluation of schedule performance when complemented with PPC (Mitropoulos, 2005). In terms of quality of the deliverable resulting from activities, Sukster (2005) proposed the Percentage of Packages Concluded with Quality (PPCQ) determined by the ratio of packages concluded with quality to the total number of packages concluded, and the Percentage of Packages Really Concluded (PPCR) determined by the ratio of packages concluded with quality to the total number of planned packages. Jang and Kim (2007) proposed Percent of Constraint Removal (PCR), to measure the performance of the make ready process. Alarcón et al. (2014) observed that for successful projects, it is not sufficient to possess high values of PPC and PCR; it is also essential to control their variability.

The above is a sample of the most relevant LPS metrics which, in all cases, are deterministic and do not arise from statistical modeling. In terms of variability assessment, Emdanat et. al. (2016) proposed the Percent Required Completed or Ongoing (PRCO), which evaluates the percentage of required activities completed by their promised dates, encompassing ongoing activities projected for completion by their original promised dates after team members update remaining durations to align with remaining work. Additionally, they introduced the Milestone Variance (MV), denoting the gap in days between the anticipated completion date for all pending tasks and the milestone's prescribed deadline. Although these last-mentioned indicators are an attempt to analyze activity variation, all of this still remains within a deterministic estimation realm.

When it comes to simulation experiments, studies are founded on simulating process behavior to offer valuable insights, though new specific stochastic indicators are not provided. In this regard, Tommelein (1997) conducted a simulation that enabled experimentation through modeling push- and pull-driven sequencing of resources. Likewise, Hamzeh and Langerud (2011) conducted a simulation to study the relationship between increasing Task Anticipated (TA) and PPC increase, and the concerning impact on project performance. The study results showed that even a small change in TA may significantly affect PPC. More recently, there have been approaches to simulation games such as that proposed by Alves et al. (2022), who presented an analogue simulation game concerning Takt Time Planning (TTP) and Takt Control (TC) and showed, employing a case study, one way in which Lean Construction and Building Information Modeling (BIM) can be linked through QR codes. In author's opinion, concerning BIM models can serve as a graphical base for running future stochastic analysis.

ASSESSMENT OF PPC UNDERSTANDING

POLL RESULTS ON PPC UNDERSTANDING

The term *completion* is commonly used in LPS literature, typically in relation to activities. Therefore, *activities completion* implies that there is nothing more to add to those activities. However, there is a trend among Peruvian LPS practitioners to measure this in terms of quantities related to finished activities instead of completed deliverables. In this paper, a deliverable is considered complete only when technical requirements are met, signifying that the presence of defects indicates a lack of requirement compliance.

In this context, a survey was conducted with the aim of assessing the knowledge of PPC estimation among Peruvian LPS practitioners (see Table 1). To achieve this, a survey database built in Peru was selected, indicating that a majority of the emails correspond to this country. In this regard, preliminary observations derived from the results might be mostly applicable to Peru. The survey question was intended to replicate the common questions raised when estimating the PPC, and it includes a section regarding defects, stating that it has a delimited impact. The question was as follows:

"Considering that PPC is the percentage of plan completed, answer the following: There are 10 concrete slabs, each with a volume of 5m3. If you plan for 10 concrete-cast activities in a week and 9 of these activities are done within that time period, what is the value of PPC? Taking into account that the strength of the slabs is satisfactory; there are pending corrections, but they impact a maximum of 10% of the time or resources."

Table 1. Survey specs on PPC estimate

Location	Peru	**% Peru responders**	52.2%
Size	45	**% other countries**	47.8%
Mean	Emailing, WhatsApp	**Dates**	15 to 26 Jan, 2024
Tool	Google Forms	**LPS Years Exp. (LPSYE) Avg.**	4.13
Source	Database built in Peru	**LPSYE Standard Deviation**	3.31

To answer this question, it should be note that an activity finalized with a slab with pending corrections is actually *not completed*, then it remains as *work in progress*. The correct answer to the question above is *Need More Data*, as the number of not completed slabs (resulting from unproperly finalized activities) can vary and is not mentioned.

Figure 1 helps to explain why we need more data to answer the question. Here, NS means *not started*, WIP means *work in progress*, indicating either started activities not yet finished or the presence of defects, signifying incompleteness. Finally, OK means *complete*, denoting full technical requirement compliance. The first alternative indicates a real PPC equal to 90% as there are no defects, and activity finalization did not result in incomplete slabs (there is no pending corrections); here, the nine resulting slabs are OK. On the other hand, the rest of the possible alternatives show concrete-casted slabs, but there are defects affecting a different number of slabs tagged as WIP; those defects have the same impact in any alternative, as the impact is measured in terms of time or resources (10% impact as per the question), not in terms of deliverables. PPC estimates are based on activities and will differ from deliverable-based estimates if those activities are *wrongly assumed to be finalized with defects-free slabs*.

Figure 1. Number of slabs at different completion states related to the answer for the Poll on PPC estimate

Thus, to respond to the poll question, we require data regarding the number of deliverables associated with activities. Furthermore, considering the Lean Philosophy's emphasis on delivering value to the client, the inclusion of deliverables in PPC assessment is crucial, as they encapsulate the value created by the project. The results in Figure 2 shows the value of 90% as the most selected answer to the poll. Yet, the sample size is statistically not representative and need to be increased, these results are very consistent with the hypothesis that, in Peru, PPC is solely assessed based on activities without delving into the results, wrongly assuming that the results (deliverables) are in accordance with requirements. As quality is defined as the degree to which a set of inherent characteristics of an object fulfils requirements (ISO, 2015) then quality, in essence, is assumed, not assessed when estimating PPC for this population.

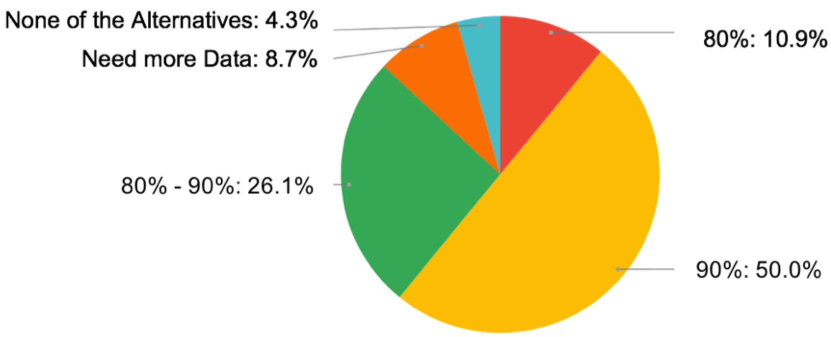

Figure 2. Proportions in answers for the poll on PPC estimate knowledge

A more extensive poll, displaying the same pattern, would suggest that common LPS practitioners make no further analysis of activities' results and consequently fall into wrong assumptions about completion and planning. The author doesn't claim that LPS practitioners usually wrongly estimate PPC but states that there might be a bias in the first glance assessment of PPC that may lead to wrong PPC estimates in Peru.

NEW METRICS DEFINITION

PPC+ AND PPC++

Percent Plan Complete (PPC) is the percentage obtained by dividing the number of completed planned activities by the total number of planned activities (Ballard, 2000). PPC is a well proven way for measuring schedule reliability and is used as a basis for an additional set of metrics introduced in this paper called PPC+ and PPC++. PPC variability may reduce and average PPC value may also increase in a given set of periods of time converging to 100%. Then, assuming that it consistently reaches the 100% for a set of periods, intuition may lead us to believe that there is no more variability to address; however, another kind of hidden variability remains, and can be out of control yet. The hidden variability is related to daily changes (back and forth leaps) in scheduled activities execution and reworks required at deliverables level, compromising completion; all of this is not measured by PPC. In some situations, changes in the sequence can result in poor quality, which might affect subsequent work, potentially necessitating the need for rework at later stages of the project (Fireman et al., 2013).

In the figures of this section the author explains these situations. Here, every activity is independent of one another, and there is no constraint to reschedule any of them ahead of or after the schedule. Furthermore, all activities are carried out in the same shown week.

Figure 3 illustrates five scheduled activities, each of them pertaining to a specific deliverable (e.g., concrete casting for one column). The assignment of two laborers for one activity every day is taken into account. In this scenario, the expected performance of two laborers is estimated to be *well*, achieving the completion of one column per day. It is noteworthy that in this example, no additional deliverable-related activities are introduced. In Figure 3, it can be also observed that when each column is completed on the respective day, the PPC equals 100%. This value remains consistent even if activities are rescheduled during the same week.

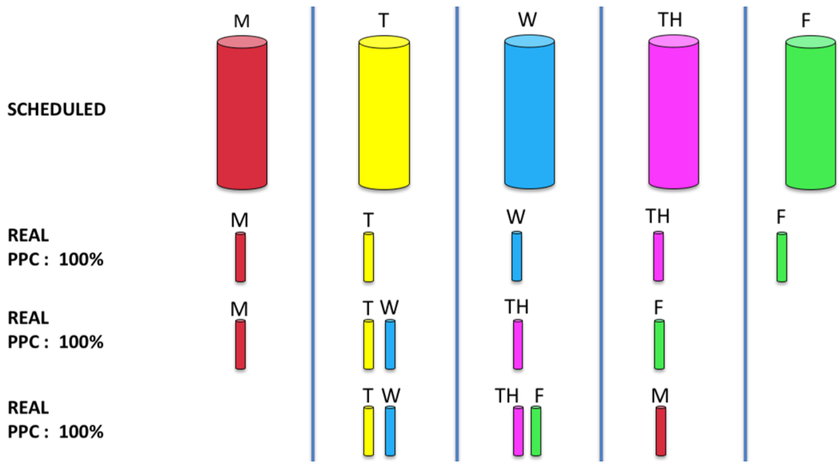

Figure 3: Common PPC estimate in Peru as per author's observation (Samaniego, 2021)

In Figure 4 PPC+ is estimated by taking into account only concrete casting activities done when scheduled. Thus said, there are only three activities completed when required, then PPC+ equals to 60%. In Figure 5, for obtaining PPC++ only concrete casting activities are taken into account if the resulting deliverable (column) is completed as daily scheduled – that means according to requirements and then free of defects; in this sense, as there are only two successful activities, then PPC++ equals to 40%.

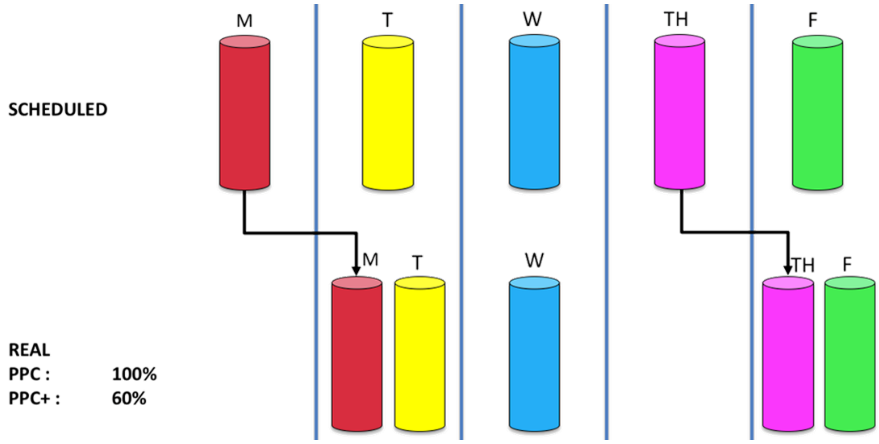

Figure 4: Application of PPC+ (Samaniego, 2019)

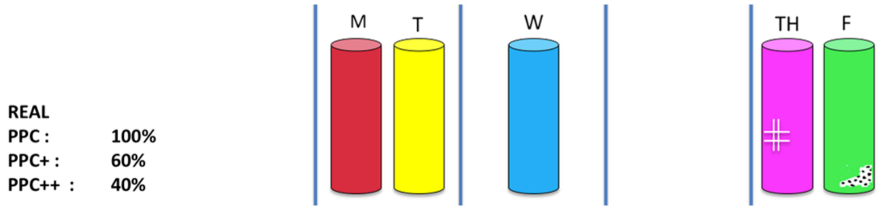

Figure 5: Application of PPC++ (Samaniego, 2019)

The author anticipates that both PPC+ and PPC++ will be subject to constant variability, even though PPC consistently reaches 100%, as shown in Figure 3. Additionally, defects will later lead to informal rework packages (Fireman et al., 2013), and the impact of defects is unveiled by PPC++.

RPA AND RW

Taken into account Figure 3, it can be seen that the number of possible combinations of PPC+ for a given PPC at 100% is equal to 5^5, meaning 3,125 outcomes. Then, it is possible to obtain the different values for PPC+ and define the most frequent as PPC+r. The relation between the PPC+ site obtained and the PPC+ randomly obtained (PPC+r) defines the Rpa (Ratio of Planning Assessment) as follows:

$$R_{pa} = \frac{PPC +}{PPC +_{r}}$$

In regards to resource usage, in the model, it can be seen that since there are days where *two* columns are concrete casted by *one labor* (e.g., Tuesday), then the previous well estimated one column per *two labor* day proves to be wrong, meaning that there is one labor in excess; so, there is room for improving labor efficiency. These unnoticed added resources (two labor instead of one labor) are the way schedulers face uncertainty and variability. This is a kind of capacity buffer to reduce the impact of variability on a system's operation at different locations along the chain (Hamzeh, 2009). As the PPC+ only considers the activities done when actually scheduled, it will be equal to PPC only when full labor resources are used when scheduled. Thus, the following relation defines the ratio of wasted resources (Rw):

$$R_w = \frac{PPC +}{PPC}$$

Thus said, in given e.g. ten weeks where ordinarily applied PPC could consistently reach 100%, there is, apparently, an optimal case not only due to PPC value but also due to zero variation. However, any of these weeks could have a huge range of PPC+ and/or PPC++ values, as per the example above.

SIMULATION AND THEORETICAL RESULTS

In this section, the study utilizes the theoretical case described in Figure 3, where three possible outcomes demonstrate variability in PPC+ and PPC++ for a constant 100% PPC value. The simulation will consider all possible outcomes from randomness and define the most probable value for PPC+. Thus, by defining the Rpa, this paper links PPC+ with PPC+r, which represents PPC+ estimated from a random scheme.

SIMULATION FOR PPC+

The author organized the data in a spreadsheet for the case under study (see Table 2). In this arrangement, '0' indicates that the activity was completed as scheduled, '-1' signifies that the activity was finalized one day earlier, and '+1' indicates a one-day delay. This is what is called back and forth leaps. There are 3,125 combinations, as aforementioned. One section of the combination record is shown in Table 2. In Table 3 and Figure 6, It can be observed that the most common random PPC+ for this case is equal to 20%. Therefore, any PPC+ result site-obtained close to 20% indicates poor plan execution, as it aligns with the most probable random outcomes. Conversely, a PPC+ close to 80% is highly uncommon, signifying a deviation from randomness and alignment with planned results, indicating good planning and execution.

Table 2. Sample showing rescheduled activities combination with related PPC+ values

ID	M	T	W	T	F	PPC+
1	0	-1	-2	-3	-4	20.0%
2	0	-1	-2	-3	-3	20.0%
…	…	…	…	…	…	…
3124	4	3	2	1	-1	0%
3125	4	3	2	1	0	20.00%

Table 3. Frequency of PPC+r

$PPC+_r$	Occurrences	Frequency (F)
0.0%	1024	32.8%
20.0%	1280	41.0%
40.0%	640	20.5%
60.0%	160	5.1%
80.0%	20	0.6%
100.0%	1	0.0%
Grand Total	**3125**	

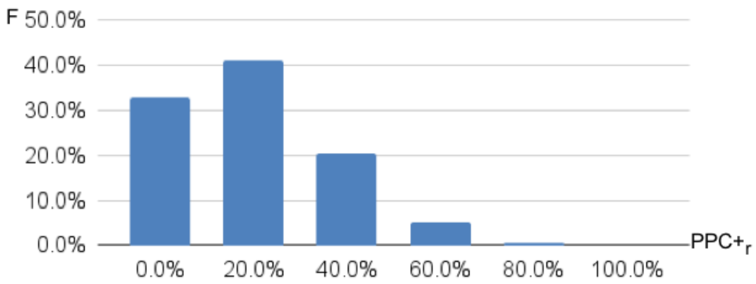

Figure 6. Frequency distribution for PPC+$_r$

Also, Table 4 presents the rescheduling frequency in a random scheme; here, the most frequent value pertains to the not rescheduled activity represented by the ‘0’ value. This symmetrical distribution is expected given the conditions for this scheme explained before.

Table 4. Number of activities rescheduled (back and forth leaps)

Leaps (L)	-4	-3	-2	-1	0	1	2	3	4
Leaps Number (LN)	625	1250	1875	2500	3125	2500	1875	1250	625
Leaps Freq. (LQ)	4.0%	8.0%	12.0 %	16.0 %	20.0 %	16.0 %	12.0 %	8.0%	4.0%

It is worth noting that in a regular project, a trend of delays is the norm. This is addressed to ensure compliance with the weekly schedule, as illustrated by one hypothetical weekly progress recovery curve (dotted curve) in Figure 7. The preventive weekly acceleration curve (continuous curve) depicts the opposite hypothetical pattern in order to keep progress on track, reflecting an intentional early acceleration trend to achieve the weekly schedule. In both cases, this is only possible if labor resources are in excess, and their usage efficiency can be unveiled by Rw. Both hypothetical curves show a schedule compression, this can also biases workers towards getting their tasks done, even when that means spending less time on validation and quality assurance (Ford et al., 2003). Analyzing this, along with trends in site-obtained Rw, can illuminate how excess capacity can be optimally utilized, resulting in cost savings for the project. On the other hand, Table 5 and Figure 8 present the Rpa behavior for different values of a given PPC+r. As the most probable PPC+r value is 0.2, a higher Rpa approaching 5 indicates that the results deviate significantly from randomness, attributed to PPC+ equaling 1.

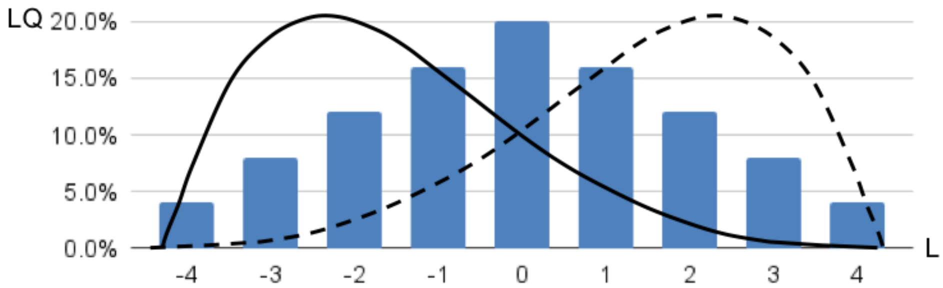

Figure 7. Symmetrical rescheduled activities (back and forth leaps)

Table 5. Rpa value per different PPC+r values

PPC+	PPC+r	Rpa
1	0.0%	---
1	20.0%	5
1	40.0%	2.5
1	60.0%	1.67
1	80.0%	1.25
1	100.0%	1

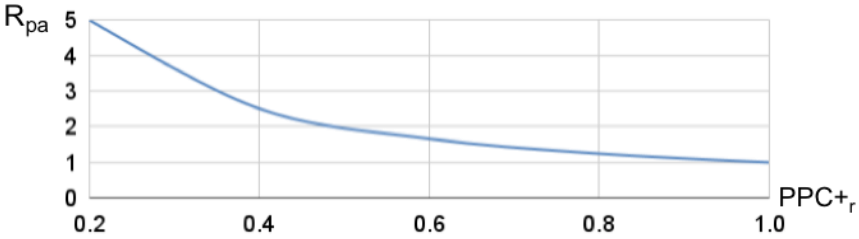

Figure 8. R_{pa} curve per $PPC+_r$ value

SITE RESEARCH PROJECT

The points of departure of this study are based on observations described in this paper, which pertains to misconceptions among LPS practitioners in Peru on completion and PPC. An extended research can be done to strength these observations by: (1) Conducting extended polls about concepts exhibited in this paper among LPS practitioners; (2) Running focus groups among both senior and junior LPS practitioners; (3) Reviewing PPC estimates in active projects. In respect to the new metrics, site validation experiments should consider the following: (1) Conducting experiments in five building projects (towers); (2) Senior LPS practitioners works in the aforementioned projects; (3) The selected project portion shall contain activities independent of one another, without any constraint to move them back of forth (to replicate the conditions of the presented simulation); 4) Daily recording of new indicators and researcher's immersion in the project for a period of one month and applied to selected trade(s).

CONCLUSIONS

This study provided an overview of key LPS metrics developed thus far, with PPC being the most frequently used metric in the industry. While LPS has been proven to enhance planning reliability and reduce workflow variability, there is still room for improvement by identifying hidden variability not yet addressed by LPS deterministic metrics. Additional metrics, PPC+, PPC++, PPC+r, Rw, and Rpa, are presented to address hidden variability and reveal hidden resource waste. Among all of them, Rpa stands out as a pioneering stochastic indicator for the LPS framework.

The study presents a new focus on deliverable completion, which differs from the common focus on activity completion. The consistent results of the polls, though small, provide insights for future studies on PPC estimates and decision-making processes related to completion achievement. In light of this, a research project is proposed to strengthen the findings on LPS Peruvian practitioners' completion understanding. To address related misconceptions, the study provides PPC++, which, in addition to measuring what PPC+ does, adds the criterion of physical deliverable completion. Thus, PPC++ assess if there are zero non-compliances with technical requirements related to properties and characteristics of the deliverable; in other words, PPC++ also serves as a brand new LPS quality metric for deliverables. As planned results are the opposite of random results, and the closer the results are to randomness, the poorer the planning was, a stochastic indicator (Rpa) was developed to provide a random value against which performance results can be compared. In this development, a simulation was conducted on a delimited process model, based on the number of possible combinations of activity leaps, resulting in the most probable value for PPC+ in a random situation (PPC+r). Thus said, should site obtained PPC+ closes to PPC+r, the poorer plan execution was, as this relation is shown by Rpa. Additionally, as the study shows that in order for the activities leaps to exist, there is a need for sunk additional resources, this study proposes Rw (which relates PPC to PPC+), shedding light on hidden resource excess to address variability expressed in activities' back and forth leaps. Finally, the study provides a foundation and directions for further research and on-site validation to refine and expand the application of these novel metrics.

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