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USING REASONS FOR NON-COMPLIANCE TO ASSESS PROJECT PERFORMANCE IN THE LAST PLANNER SYSTEM®

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ABSTRACT

The Last Planner System® (LPS) follows a systematic process of planning and control, in which compliance to short-term commitments is followed weekly and Reasons for Non-Compliance (RNC) are traced for each commitment not accomplished. While most project managers pay close attention to the evolution of the Plan Percent Complete (PPC) indicator to assess project performance, many projects make little or no use of historical data regarding RNCs. The aim of this research is to use quantitative RNC measurements to detect if projects with successful schedule accomplishment present significant differences in their number of RNC, their composition and impact. We gathered weekly information from 23 complete Chilean industrial construction projects and used the Schedule Performance Index (SPI) and Schedule Deviation (SD) at completion to categorize projects into two success groups. We compared LPS compliance indicators between the two groups, such as the Plan Percent Complete (PPC), and RNC metrics, such as their Relative Importance Index (RII), the percentage of internal RNC and the percentage of RNC caused by the main contractor. We found that RNC metrics present significant differences between the groups and can help project managers to establish actions for continuous improvement.

KEYWORDS

Lean Construction, Last Planner System®, continuous improvement, Reasons for Non-Compliance.

INTRODUCTION

AIM AND SCOPE OF THE RESEARCH

Most project control metrics are based on the amount of work performed, efficiency and efficacy in achieving goals, whilst few metrics are focused on the quantity, composition and impact of recurrent problems, which can help detect and prevent project deviations (Hamzeh, El Samad, and Emdanat 2019; Samad, Hamzeh, and Emdanat 2017). Our aim

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is to understand how the measurement of Reasons for Non-Compliances (RNCs) in the Last Planner System (LPS) can complement the assessment of schedule performance.

We addressed the research question: What statistically significant differences can be detected in the composition and impact of RNCs between industrial construction projects with different schedule accomplishment? And three objectives were set: (1) create standardized metrics to categorize projects based on schedule performance, (2) identify differences in common LPS indicators between successful and less-than successful projects and (3) propose quantitative RNC metrics that allow to significantly differentiate successful and less-than successful projects. We focused on industrial construction projects since most of previous research has addressed mainly high-rise and residential building projects (Alarcón et al. 2008; Daniel, Pasquire, and Dickens 2015).

We used a sample of 23 complete industrial construction projects that used the software IMPERA to sustain LPS, and addressed differences in their LPS indicators and RNCs. IMPERA was created by the Pontifical Catholic University of Chile to sustain a complete, standardized, implementation of LPS and allow the systematical collection of project performance data (Alarcón and Calderón 2003). It has been implemented in more than 480 projects and its database has been used in several research projects (Alarcón, Salvatierra, and Letelier 2014; Lagos, Herrera, and Alarcón 2019).

TRADITIONAL APPROACH TO PROJECT MANAGEMENT

Projects face uncertainty and variability (Howell, Laufer, and Ballard 1993; Koskela 1999). Hence, managers face limitations when planning their execution in advance due to complexity and internal or external factors that can cause variation, such as economics, supply, labour or productivity (Howell, Laufer, and Ballard 1993). The traditional approach to manage uncertainty has been to place time buffers between activities, that allow a determined variation to occur without affecting the schedule (Ballard 2000). Variability increases over the consecutive execution of subsequent activities and time buffers prevent its detection until significant deviations in project schedule are observed (Gonzalez, Alarcón, and Mundaca 2008; Zegarra and Alarcón 2017).

TRADITIONAL PROJECT CONTROL SYSTEMS

Systematic control based on Key Performance Indicators (KPI) is critical to prevent deviations and adjust plans (Chan and Chan 2004; Sarhan and Fox 2012). Traditional control uses result-oriented KPI to address cost, time and scope. Most traditional metrics assess the schedule and budget based on the Earned Value Method (EVM) (Abdel Azeem, Hosny, and Ibrahim 2014; Lipke et al. 2009; Sarhan and Fox 2012). EVM uses detailed schedules with resource allocation to construct planned and actual progress curves, were earned schedule and budget are measured (Abdel Azeem, Hosny, and Ibrahim 2014). Table 1 shows the KPI used to track schedule accomplishment in EVM. These metrics aggregate the value earned by all the activities executed to construct an overall progress index, compare it to the expected progress and determine rates of accomplishment and deviation and, thus, can hide variability when compensating the deviations from different activities (Alarcón, Salvatierra, and Letelier 2014; Sarhan and Fox 2012).

The use of result-oriented KPI has been criticized as lagging control, since they measure results rather than processes (Toor and Ogunlana 2010). Also, relying on buffers prevents the detection of early signs of variability, because they can be expended and project goals can still be achieved, but the margin for future variation reduces. Process-oriented indicators can aid to control the variability in process execution, but, their complementary use with process-oriented KPI is far less common practice than the strict dependency on result-oriented KPI (Sarhan and Fox 2012; Toor and Ogunlana 2010).

Table 1: Earned Value Method Indicators (Lipke et al., 2009; Azeem et al., 2014)

Indicator	Formula	Description
Schedule Performance Index (SPI)	EV / PV	Earned Value over Planned Value, measured by cost or workdays
Schedule Variance (SV)	EV - PV	Difference between Earned Value and Planned Value, measured by cost or workdays
Time Variance (TV)	ES - AT	Difference, in days, between the Earned Schedule and actual date of control
Schedule Deviation (SD)	(ES - AT) / ES	Difference between Earned Schedule and Actual Date, over Earned Schedule, in percent

The Lean Construction community has proposed to integrate process and result oriented systems of control through the Last Planner System (Ballard 2000). In LPS, project managers pay great attention to the accomplishment of short-term schedules and register the recurrence of common problems affecting the short-term plans (Howell and Koskela 2000), thus allowing to systematically assess variability and its causes.

THE LAST PLANNER SYSTEM ®

LPS manages projects in three scopes (Ballard 2000; Ballard and Tommelein 2016). First, Long term plans define the basic schedule milestones, which are planned from end to finish, using a method called Phase Scheduling (PS). PS allows managers to create flexible plans without hiding float and then explicitly allocate activity buffers when float is needed between milestones. Second, the Lookahead Plan (LP) represents the mid-term, comprised of activities in a 3 to 12 weeks horizon. Every week, new activities are added to the LP to maintain the horizon and the team searches for mid-term constraints. Constraints are managed to prepare work and constraint-free tasks that compose the Workable Backlog (WB) are pulled to the short-term period. The WB is used at the third planning scope to develop short-term schedules, usually comprised of one to two weeks, were tasks are analysed with the workforce to develop execution commitments.

LPS exercises control at the three scopes. Traditional methods such as EVM are used to monitor schedule, budget and scope at the long-term (Novinsky et al. 2018; Ponz-Tienda et al. 2015). At mid-term, control is focused on work preparation and constraint removal. Tasks Made-Ready (TMR) measures the WB over the number of tasks planned for the upcoming week in the LP to assess work preparation (Hamzeh and Aridi 2013), while Percent Constraints Removed (PCR) measures the number of constraints removed over the number of constraints planned for the upcoming week (Lagos, Herrera, and Alarcón 2019). At the short-term, Percent Plan Complete (PPC) measures the number of accomplishments over the number of tasks committed and a Reason for Non-Compliance (RNC), which is a standardized type of problem linked to a specific cause and root source, is registered for each unaccomplished commitment (Ballard and Tommelein 2016).

NEED FOR NEW METRICS IN THE LAST PLANNER SYSTEM

LPS has proven to be highly beneficial to project management, increasing productivity, reducing variability and improving performance (Alarcón et al. 2008; Ballard and

Tommelein 2016; Daniel, Pasquire, and Dickens 2015; Liu, Ballard, and Ibbs 2011). Although, researchers have found that most projects present partial implementations, focusing mostly on short-term planning (Daniel, Pasquire, and Dickens 2015; Dave, Hämäläinen, and Koskela 2015). We reviewed the cientific research carried out by the Lean Construction community between 2009 and 2019 regarding LPS and the contributions made to improve their understanding and deployment, in order to identify the needs and opportunities to improve LPS implementation. We found that most projects use compliance indicators such as the PPC only to make short-term adjustments, while few used the historical information of PPC, PCR or RNC to take long-term actions for continuous improvement (Dave, Hämäläinen, and Koskela 2015). The lack of focus on mid and long term is found to be due, partly, to the lack of understanding of how LPS information can help assess long term objectives and partly due to the need of quantitative research to establish success criteria for LPS metrics aligned with long term objectives (Daniel, Pasquire, and Dickens 2015; Hamzeh, El Samad, and Emdanat 2019).

Several metrics that show the relationship between work preparation, short-term compliance and project performance have been proposed to alingn the short and long term scopes (Hamzeh, El Samad, and Emdanat 2019; Kim 2019; Liu, Ballard, and Ibbs 2011; Samad, Hamzeh, and Emdanat 2017). Many of these have been incorporated into Information Technology (IT) support systems for LPS such as IMPERA and vPlanner, although quantitative assessments of RNCs have yet to be included (Emdanat, Linnik, and Christian 2016; Lagos, Herrera, and Alarcón 2019). Previous work shows that most projects register RNCs weekly, but the majority do not use historical RNC information to establish corrective actions and, it appears, that the use of IT support has not improved this matter yet because projects lack ways to systematically align RNC metrics to short-term indicators such as PPC and long term objectives like schedule and budget (Lagos, Alarcón, and Salvatierra 2016; Lagos, Herrera, and Alarcón 2019). Altough, the increasing adoption of IT support presents the opportunity to automatically quantify the impact of RNC and link it to short and long term compliance metrics such as the PCR, PPC and SPI, to establish success criteria (Dave, Hämäläinen, and Koskela 2015; Emdanat, Linnik, and Christian 2016; Lagos, Herrera, and Alarcón 2019).

RESEARCH METHODOLOGY

SAMPLE SELECTION

We found 23 industrial construction projects, from 5 Chilean companies, that used IMPERA to register weekly information since less than 10% progress and until completion. They registered compliance indicators for progress (SPI), schedule accomplishment (SD), commitment compliance (PPC), constraint removal (PCR) and detailed information regarding the type, origin, impact and description for each RNC. They had an average planned duration of 33 weeks and an average real duration of 36 weeks. The sample represented a total of 773 weeks and we obtained detailed information from 654 weeks. Each project registered an average of 344 constraints, ranging from 68 to 1272, and an average of 175 RNC, ranging from 43 to 583, which means that, in average, they registered 7 RNC and 11 constraints per week.

We constructed accumulated indicators for each project using the averages from the total number of weeks in which they used IMPERA. These were the average PPC and PCR, total number of RNC, total number of constraints, and the average number of constraints and RNC per week, normalized per 100 project tasks. We also obtained two result indicators: The SPI measured at the end of the planned duration and the SD measured at project completion. In addition, we constructed standardized progress indicators by dividing the project planned duration into ten progress intervals. Each 10% planned progress interval was represented by the average PPC of that interval, the accumulated PPC average until the end of the interval and the number of RNC.

RNC composition was assessed by creating standardized categories. We categorized the source as "internal" if it originated within the management scope of the project or "external" if it was caused by third parties or uncontrollable events. We also categorized each RNC by the party that originated the problem; these could be the "Main contractor", the "Client" or "Third Parties". We used the detailed description of each RNC to establish their source and party. Table 2 shows the categories that we assessed. Finally, we determined RNC impact by dividing the percent progress achieved in each task over the progress committed for each task at each week.

Table 2: RNC Categories established for source, party and type

Source	Party
Internal: Causes that should be controllable by the project, like coordinating supplies and resource allocation.	**Main contractor:** Includes RNC such as planning errors, labour productivity, work field coordination, quality issues during execution, internal administrative procedures, etc.
External: Causes that are uncontrollable like climate issues and accidents, or controlled by third parties like delays in supply and changes in regulatory limitations.	**Client:** Includes design changes and delays, mandatory work detention requirements, delivery of work field and permits, etc.
	Third parties: Includes RNC caused by suppliers, subcontractors or other contractors in the work field, inspectors and externals.

PERFORMANCE CATEGORIZATION

We classified project outcome using schedule measurements, namely their final SPI and SD. We used a two dimensional K-means algorithm to create clusters with similar results regarding schedule accomplishment (Jain 2010), using their SPI and SD. The algorithm created four randomly located centroids and assigned each project to its closest centroid, creating four clusters. Then, it moved each original centroid to the center point of each cluster and repeated the allocation process, until no significant changes were observed between the clusters composition. Each group obtained was composed projects with a similar result. The first cluster represented highly successful projects and the fourth group represented the projects furthest from success, while the separation between the two center clusters represented the classification rule obtained to segregate successful and less-than successful projects. We obtained 11 projects that failed to meet schedule and 12 successful projects that performed according to their planned schedule or better.

ANALYSIS OF DIFFERENCES BETWEEN GROUP INDICATORS

We analysed the existence of differences between the accumulated indicators from the two groups using statistical test for mean differences. First, we used the Shapiro Wilk to determine which samples followed a normal distribution. The null hypothesis "the sample follows a normal distribution" was tested using a 95% confidence interval and it could be rejected when the resulting p-value was higher than 0.05 (Hernández, Fernández, and Baptista 2006). We applied the t-test to establish differences in the means between the two groups when we could not reject the null hypothesis in any of the groups and used the Mann Whitney U test for the remaining samples. We used the null hypothesis "There is no significant difference between the groups" in both tests using a 95% confidence level, meaning that it could be rejected when the p-value was equal or lower than 0.05 (Hernández, Fernández, and Baptista 2006). We used this test for each of the accumulated indicators and also for the accumulated and partial PPC of each interval.

ANALYSIS OF DIFFERENCES IN RNC COMPOSITION

We used the total number of RNC by source in each project to construct a Percent Internal RNC (PIR) indicator, which allowed to determine which RNC source was most relevant in each project. PIR was calculated as the number of RNC catalogued as internal over the entire number of RNC for each project. We constructed a similar indicator for party, the "Percent of RNC caused by the main contractor", that measures the number of RNC caused by the main contractor over the entire number of RNC for each project, thus, allowing to assess whether the majority of the RNC originated under the contractor management or were caused by other parties. In addition, we constructed an indicator to compare the relevance of a determined category of RNC. This indicator was based on the Relative Importance Index (RII) which has been used previously to compare different factors and causes of project delay (Aziz 2013; Gebrehiwet and Luo 2017).

RII measures the weighted frequency of a response, usually in a qualitative Likert scale, over the frequent of the responses. This means that, for example, if a three-point Likert scale is used for weight types of RNC and the majority of the responders assigned 2 points to a determined type, while a few of them assigned 3 points, then the RII will be slightly higher than 2. Since we counted with quantitative data por frequency and average impact, we modified the RII, creating the Quantitative Relative Importance Index (QRII), which uses impact instead of weight responses, multiplies it by the frequency for a determined category and then divides it for the average result of all the categories. Table 3 shows an example of QRII calculation. We used the QRII to determine a ranking of RNC and then compared the QRII between the successful and less-than successful groups.

Table 3: Example of QRII calculation method

RNC by party	Frequency	Impact	Weighted relevance (WR)	QRII
Description	*Number of observations*	*Average deviation in planned progress*	Frequency * Impact	WR_i / average WR_n
Main contractor	2170	53%	1158	1.46
Client	1312	60%	783	0.99
Third parties	835	53%	439	0.55
Average	1439	55%	793	1

CORRELATION ANALYSIS BETWEEN RNC COMPOSITION AND RESULT

After establishing quantitative metrics for RNC composition, we tested correlations between the percentage of internal RNC, the percentage of RNC caused by the main contractor, the SPI and SV, over the entire sample. We used the Pearson correlation coefficient r and considered the existence of a moderate correlation when the absolute value of r was equal or higher than 0.4, strong when it was equal or greater than 0.6 and highly-strong if it was equal or greater than 0.8 (Hernández, Fernández, and Baptista 2006).

RESULTS

PERFORMANCE CATEGORIZATION

The clustering results showed that the successful project groups had a SD equal or lower than 5% and a SPI equal or higher than 96%. If a project did not fulfil any of the criteria, it was categorized as less-than successful in terms of schedule accomplishment. Figure 1 shows the project segregation results.

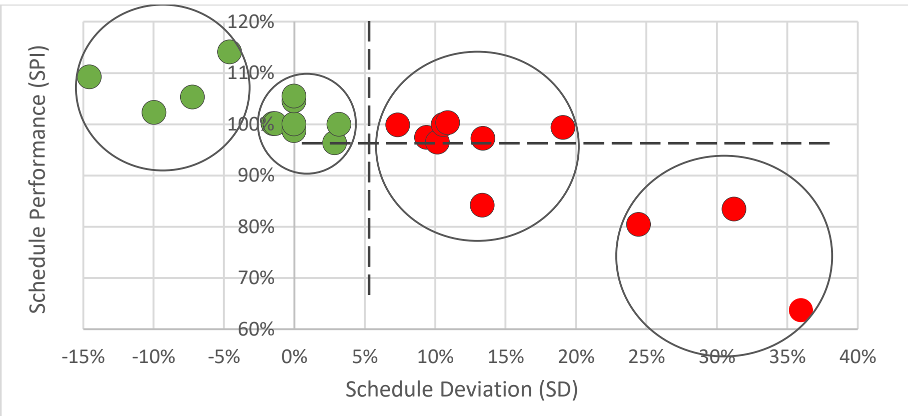

Figure 1: Project categorization based on schedule accomplishment clustering

DIFFERENCES IN THE ACCUMULATED INDICATORS

We were not able to find significant differences between the groups regarding the PPC average, PCR average, RNC average and RNC per week. But, we found a significant difference in the total number of constraints and, when we normalized the average number of constraints per week by the total number of tasks in each project, we found that projects that meet their planned schedule manage twice as many constraints per task per week than projects with significant schedule deviations. Table 4 summarizes our results.

Table 4: Differences in Accumulated LPS Indicators

Group Means	Success	Failure	Difference ratio
Number of projects	12 projects	11 projects	
Final SPI	103.0%	91.1%	1.13**
Final DP	-2.8%	16.9%	6.04**
PPC Average	70.5%	66.2%	1.06
PCR Average	59.9%	67.8%	0.88
Total number of RNC	169	194	0.87
Total number of constraints	394	242	1.63*
Number of constraints per period	13,8	10,1	1.37
Constraints per period by 100 tasks	8,4	4,1	2.05*

*Significant to a 95% level **Significant to a 99% level

We also analyzed differences between the accumulated and partial PPC for the standardized progress intervals. Figure 2 shows that the partial PPC curves cross each other while the accumulated PPC curves develop a 3% to 5% gap between the groups after the first third of the project, that remains until planned completion. Nevertheless, the difference is too small and the PPC varies between projects within a group. Therefore, none of the differences observed in the accumulated PPC were significant to a 95% confidence level.

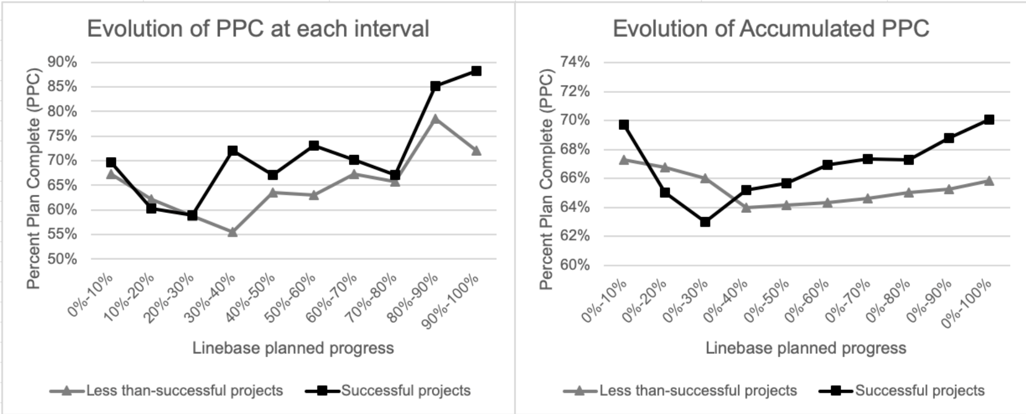

Figure 2: Evolution of the PPC in successful and less-than successful projects

DIFFERENCES IN RNC COMPOSITION

Table 5 shows the results of the analysis of percent of internal and contractor caused RNC. In addition, we compared the QRII calculated for each source and party, and finally, we calculated ratios between the QRII of internal to external source and the QRII ratio between contractor caused RNC and client caused RNC. We observe that, in successful projects, less than 40% of their RNC are due to internal causes or generated by the main contractor, while, in less-than successful projects, this causes are responsible for more than 60% of the total number of RNC.

Table 5: Quantitative indicators for RNC composition

Mean RNC indicators by group	Success	Failure	Relative difference
Percent of Internal RNC	39.8%	62.5%	1.57*
QRII Internal source	0.38	0.61	1.61*
QRII External source	0.62	0.39	0.63*
QRII ratio of internal to external causes	0.61	1.57	2.57**
Percent RNC caused by main contractor	37.8%	60.9%	1.61*
QRII Main contractor	0.54	0.92	1.70*
QRII Client	0.7	0.29	0.41*
QRII Third parties	0.27	0.28	1.04
Ratio of QRII Main Contractor to Client	0.77	3.2	4.16**

*Difference is statistically significant to a 95% level **Difference is significant to a 99% level

The QRII ratio between internal and externally caused RNCs shows that, in less-than successful projects, internally caused problems are 1.57 times more relevant than external problems. When comparing the two groups, it is observed that internally caused RNCs are 2.57 times more relevant in less-than successful projects than in successful projects. In addition, problems caused by the main contractor are 1.61 times more relevant in less-than successful projects than in successful projects. This difference increases when we analyze the QRII ratio of RNCs caused by the main contractor over RNCs caused by the client. It is observed that in successful projects, the problems caused by the client are more relevant than problems caused by the main contractor, while, in less-than successful projects, the relevance of the problems caused by the main contractor is 3.2 times the relevance of the RNCs caused by the client. This means that the probability of a deviation being caused by the main contractor is 4.16 times more probable in less-than successful projects than in successful projects. Therefore, significant differences in RNC composition and impact are found between successful and less-than successful projects.

CORRELATION BETWEEN RNC METRICS AND SCHEDULE PERFORMANCE

When analysing the correlation between the SPI, SD, percent of internal RNCs and percent of RNC caused by the main contractor, we found strong correlations between the percent of internal RNC and SD, and between the percent of main contractor caused RNCs and SD. We also found moderate correlations between the percent of internal RNC, percent of main contractor RNC and SPI. Table 6 presents the correlation results and Figure 3 represents the strongest correlation found, between the percent RNC caused by the main contractor and the Schedule Deviation. It must be noted that our results show that as the percent of the project problems that come from internal matters caused by the main contractor increases, the expected schedule performance decreases. This translates to a 5.1% increase in the schedule deviation for every 10% increase in the percent of RNC caused by the main contractor.

Table 6: Results of the correlation analyses

Pearson r correlation coefficients between indicators		
	Percent internal RNC	Percent RNC caused by the main contractor
SD	0.74*	0.77*
SPI	0.47**	0.53**

* r is considered strong if ≥0.6 and **moderate if between 0.59-0.4

DISCUSSION

We found that successful projects have a significantly different RNC composition compared to the less-than successful group. In fact, in projects that meet or surpass schedule objectives, 60.2% of their RNC belong to external sources and only 37.8% of their RNC are caused by the main contractor. When analysing the QRII ratio of contractor caused RNC to client caused RNC, we found that, in successful projects, is less probable that a deviation is caused by the main contractor than being caused by the client. In opposite, in less-than successful projects, 62.5% of the RNCs are due to internal causes and 60.9% are caused by the main contractor. Also, in less-than successful projects the RNCs caused by the main contractor are 3.2 times more relevant than the problems caused by the client.

The QRII ratio of contractor to client caused RNC shows significant differences between project groups and is found to be a relevant indicator to assess project performance. Also, we found that the Schedule Deviation in strongly correlated to the percent of internal and contractor caused RNCs. Hence, if most of the project execution problems are due to internal causes or controllable issues or originated by the main contractor, the expected project outcome will decrease.

Our findings show that assessing the source and party of origin of RNC can allow to complement the continuous control of schedule performance and help to state the relevance of collecting RNC information and using it to act on preventing recurrences, specially when these problems originate from internally controllable sources. Therefore, project managers should pay close attention to the frequency and impact of RNCs caused by different parties and try to minimize internal problems caused by the main contractor. If these problems are significantly more relevant than issues caused by the client or third parties, management should take immediate actions to prevent project deviation. Finally, these results allow the assumption that projects that learn from their RNCs and prevent future recurrences can improve their expected outcome. The validation of this assumption and understanding of the processes underlying it will require further research.

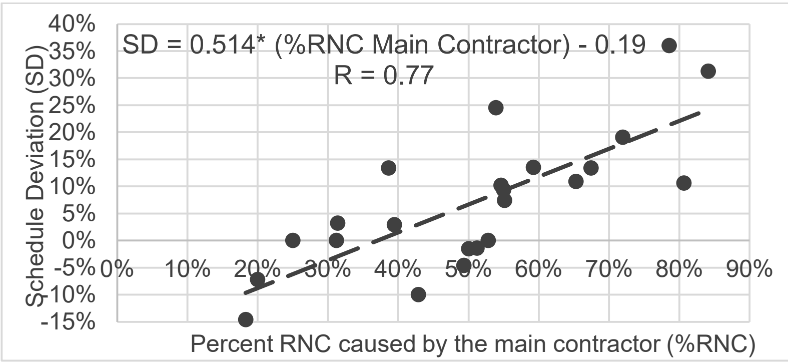

Figure 3: Correlation between SD and RNCs caused by Main Contractor

CONCLUSIONS

We found that monitoring the composition of project RNC can be complementary to the use of compliance indicators such as the PPC and result indicators such as the SPI and SD. Projects should place special effort in preventing RNC caused by their own management, since it was found that the SD was strongly correlated to the percent of internal and contractor caused RNC. Also, less-than successful projects had roughly 60% of internal and contractor caused RNC, while successful projects had less than 40%. Our QRII analysis also showed that projects should place special attention to two different planning tasks, first, coordinating workforce and resource allocation to avoid unavailability to enter the work field and, second, planning resource and design procurement in advance, with enough time buffers to avoid that delays in the client or third-party tasks affect the project short-term plans. Finally, we believe that quantitative metrics such as the percent of internal and contractor caused RNC, in addition to the QRII, can be incorporated to IT support systems such as IMPERA to help the use of historical project data in order to decide and implement long-term actions for continuous improvement with the Last Planner System.

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