Prediction of project performance: development of prediction model for predicting future performance of an OG&C project in EPC environment

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Abstract

In this paper the term Predicting project performance, refers to the capability to predict the possible future performance of EPC projects in the light of symptoms of project problems. The problems during project execution has been a source of investigation for decades now, however how can projects detect those problems before their manifestation is an area that need further development. The research associated with this paper identified the early warnings of project problems and established a predictive relationship between those identified early warnings and project performance. The relationship has been established using the dynamic analysis of information generated from past projects, which in current practices is either lost or seen in limited perspective. The results of the study show that there is a definite potential to capitalize on the factual information from past projects to improve upon the performance of current and future projects.

Key Words: Early warnings, Project performance, Performance model, Past project analysis

1. Introduction

The engineering, procurement and construction (EPC) projects in oil and chemical industry often experience problems during course of their execution. Because of those problems, some of the projects end with large cost and schedule overruns. Project management (PM) scholars and professionals have been investigating these problems over several decades now. However, a study by IPA suggested that at industry level, the performance of projects is not improving as per their expectations (Merrow, 2012). Furthermore, the current economic situation and ambition level of project owners demands to cut project implementation periods shorter and shorter (Fast tracking). Which result in a growing need to detect and react to project problems as early as possible in order to prevent these problems from causing any delays and other harmful effects on the project (Nikander, 1997). However, how well the project performance and control techniques are equipped to do that is somewhat debatable. The analysis of available literature on project control and performance management techniques suggests there has been no significant advancement and they still rely on the principle of "deviation management" (Nikander & Eloranta, 2002). It should be noted that the deviations in projects are mostly seen on aggregated level and their impact on total project performance are not clearly defined. Vanhoucke recognizes that, at higher levels, the effects of nonperforming activities can be neutralized by well performing activities, which might result in masking potential problems. These non-performing activities become more critical if they have significant effect on downstream part of project.

In addition, the forecast based on the aggregated information is highly susceptible to “optimism bias” and “planning fallacy” (Flyvbjerg & Bruzelius, 2003) i.e. unless and until there is a definitive visible problem, manager can make projections based on delusional optimism.

1.1 The Idea

The paper addresses the above fallacies in traditional performance management techniques and purposes a strategic and reality based project performance management by suggesting following ideas

1. The detection of potential problems in projects before their manifestation via their early warnings

2. The dynamic analysis of past projects to build quantitative relationships between identified early warnings and final project performance that further be can be used to build a dynamic performance prediction model.

The detection of early warnings in projects, anticipation of potential problems and predicting future performance can allow project manager to act proactively and form preventive strategies. These early preventive strategies utilize much less cost and time than correction of actual problems, thus keeping project cost and schedule with in acceptable limits.

In order to develop above ideas into usable framework or possibly a tool, the main research question to be answered is:

“***How can future problems and performance of a current O&C project be predicted at early stages using knowledge and experience from past projects in an EPC environment***?”

1.3 Research approach

The starting point of the present research is deductive in nature (Wallace, 1971). Theory of early warnings was explored in relevance to project management and subsequently project management literature is reviewed to look for early warnings in projects. On the top of literature sources, expert interviews were conducted to gain in depth and real time knowledge of early warnings in O&C project execution.

The second phase of the research is focused on the in-depth explanatory case studies. The objective of the case study investigation was to understand the dynamics between early warnings, project problems and project performance. The selected case projects include both successful and less than successful projects to set the contrast in which the differences can be visible. The case studies could provide us useful understanding of “how early warnings indicate towards manifestation of project problems that affect the project performance.” As a result, second phase has a more explanatory character.

The third phase of the research is detailed quantitative analysis that establishes the direct relationship between early warnings and project performance. For this purpose, quantitative data from past eight O&C project is collected via available project documentation such as project progress data close out reports, project status review and audit reports. The fourth and final phase of the research develops a performance prediction model using statistical modeling techniques and understanding from previous phases.

1.4 Defining project success and performance

The best-known and most used representation of project success i.e. iron triangle with time, cost and scope (or performance/quality) on its corners (See e.g. Freeman & Beale, 1992, Larsen & Gobeli, 1989, Might & Fischer, 1985) and Oisen, 1971). However, this approach has been often criticized as too narrow and broader definitions of project success are provided. Such as Moris and Hough’s three dimensions to include functionality and contractors commercial success to the iron triangle (Moris & Hough, 1987).

In presented research, the focus has been given to quantitative measurement of project success during EPC phase of the project. Therefore, perspective of an engineering and construction contractor has been adopted and following criteria is adopted for measurement of project performance, whose measurement will decide the successfulness of the project.

- Growth in TIC (TIC)
- Growth in final schedule (MCI)
- Growth in engineering manhours (MHI)
- Growth in engineering schedule (ESI)

However, it would be wrong to assume that the perspective of client and subcontractors are ignored, because to achieve the sustainable success, an engineering and construction contractor has to work collaboratively with its customer and suppliers by integrating their perception of success into its own to the possible extent.

2. Early warnings in projects

There are sources in project management literature, which presents implicit discussions about early warnings regardless of the term used in original text. Lewis presented a long list (10 pages) called “checklist for managing projects” (Lewis, 1993, Ch. 24). The absence of elements mentioned in this list could act is a cause of potential problems in projects, in other words those elements could act as potential indicators. Kerzner, Cleland and Honko (Kerzner, 1995; Cleland 1995, Honko, 1982) mention the similar lists or causes. Another relevant research titled “Leading indicators to project outcomes” was conducted by CII to identify the leading indicators that affects the project performance. However, the majority of “early warnings” mentioned in literature lacks the quantitative nature and ability of objective prediction. To compensate for the practical deficiencies in literature, 13 semi-structured interviews were conducted with experts from O&C project industry. The interviewee base included people from senior management, project directors, project managers and project control managers representing an E&C company and two different owner companies. In total, 44 early warning elements were identified from literature sources and 57 elements from expert interview. Many of the identified early warnings were similar in nature and were combined.

The identified elements included both qualitative and quantitative early warnings. However, keeping the main research question in focus, a selection criterion was formulated with following three as selection parameters.

1. Measurable – The early warnings that can be measured quantitatively or at least has the potential to be measured
2. **Early in project** - There is no reference found in literature that could define the early phase of an O&C project. Therefore, expert opinion was sought and based on the discussions; the period from start of detailed engineering, up to 75% engineering completion was defined as early. This choice can be argued based on the adequate maturity of engineering design and cost commitments at 75% completion.
3. **Data availability** – To establish the statistical relationship between early warnings and project performance, it is of utmost importance that data could be found in past projects corresponding to the selected early warnings.

After evaluation of each early warning element on above-mentioned selection criterion, 10 early warning indicators (EWI) were selected. The early warnings were rewritten and enlisted in Table 1 with sources they were identified from and possible sources of their detection during project execution.

Table 1: Selected early warnings

EWI	Early warning	Sources of detection	Identified from
LES	Lack of understanding of project execution strategy among project	Project review meeting, Project	CII-2006, IPA-2012, Kerzner-95

	team	surveys	
PTE	Project team lacks experience required for the project	Deficiency in required and actual deployed resources	Expert Interviews CII-2006, IPA-2012, Bosch-rekveldt, 2011
COC	Conflicts between owner and E&C contractor	Client survey, review meetings, contractual disagreements	Kleim and Ludin-94, Bosch-rekveldt, 2011
NCO	Numbers of change orders	Change order log	Expert Interviews, Love et al. 2002
CCO	Cost impact of changes	Change order log	Expert Interviews, Love et al. 2002.
FED	Percentage of missing information in FEED package	IPA audit report Gate C review	Expert Interviews IPA,-2012, CII-2012, Bosch-rekveldt, 2011
PH	Growth in process man-hours	Progress reports	Expert Interviews
PS	Delay in process engineering	Progress reports	Expert Interviews
CE	Change in concurrency level between process and piping engineering	Discipline progress curves	Expert Interviews ,Obradovitch - 90
DPO	Delay in issuance of purchase orders	Procurement progress curves	Expert Interviews

Although, the first three EWI are qualitative in nature and no corresponding quantitative information can be traced back in past projects. However, the analysis of literature and interviews suggested that the quality of project team and its integration does play an important role in making a difference between successful and unsuccessful projects (11 Experts, IPA-2012, Bosch-rekveldt, 2011; Kerzner-95). Therefore, it seemed logical to include them in case study analysis and test their potential as early warnings.

The EWI NCO and CCO refer to the management of changes during project execution. Changes are generally seen as detrimental to the health of a project, and proved to have major negative impact on project cost and schedule (13 experts, IPA, 2012; CII, 2006; Love et al, 2002). It is also well documented that the cumulative impact of numbers of small changes is much greater than sum of individual impacts. This is mainly due the fact that the changes not only brings new addition of work, but also produces out of sequence activities and disruption effect on ongoing activities.

The next EWI, FED refers to the quality of front-end design at the start of the EPC phase of the project. A poorly developed front-end design often result into late design changes and rework during detailed engineering phase (13 Expert interviews, IPA-2012, CII, 2012).

The EWI, PH refers to the performance of process engineering in terms of its manhours. Manhours are direction representation of amount of efforts required to perform an activity. Therefore, growth in process hours could be seen as an indicator of additional efforts (in terms of schedule and hours) process engineering need to make to deliver their inputs to downstream disciplines. If the reasons for additional efforts are related to scope of downstream disciplines, it could be concluded that the downstream disciplines will also need additional hours and project need more cost and time to accommodate these efforts (Expert interviews).

The delay in process engineering (PS) implies that the critical documents will be issued with delay, thus affecting the downstream disciplines in terms of work front and delay in their respective deliverables. In addition, the delay in process engineering impacts the procurement cycle for the project and this could result into late delivery of material and ultimately construction delay.

The EWI, CE represents change in concurrency level between process and piping engineering. From the analysis of arguments mentioned in literature and by experts, it could be concluded that the concurrent engineering execution model is directly proportional to the level of assumption being made in project (Expert interviews; Obradovitch – 90). From an early warning perspective, it seemed logical to identify the change in concurrency levels early in the detailed engineering to have a check, if design is being carried on high level of assumptions. Generally, in the O&C projects, piping engineering constitutes of substantial part of engineering and material cost therefore, if the assumptions are proven otherwise, there exist a substantial risk of high impact of total project cost and schedule.

The last EWI DPO refers to the delay in issuance of purchase orders for main equipments and critical instruments. The equipments and instruments are not only required at construction, but they also form a critical part of detailed engineering design, as many engineering deliverables are based on the information to be provided by equipment vendors. Delay in issuing of purchase orders can have impact on the vendor information required for design.

3. Case studies

3.1 Case study design

For this section, a multiple case embedded design is used in which each case represents a completed project (Yin, 2002). The primary data sources for case studies included written project achieves such as project close out reports, monthly status reports, audit reviews and other relevant document which is related to project problems.

The performance of project is defined in terms of meeting their schedule and "as sold" cost estimates. The cases selected for the study, covers both successful and less than successful projects. The successful project can provide contrast in which the prediction capability of early warnings is more visible. Under this hypothesis, the early warnings in less than successful performance project should be clearly visible or at-least have quantitative values different from their values in successful projects.

3.2 Case study results

The analysis of the case projects suggests that higher numbers of early earnings were detected in less than successful projects as compared to successful project. Furthermore, in successful project, the detected early warnings hold values that were seen as favorable by project team and do not contributed to any major project problems. The summary of case study analysis is shown in following table

Table 2: Cross case analysis

Early warning	Case projects			
	A	B	C	D
LES	√	X	X	√
PTE	√	X	X	√
COC	√	X	X	√
NCO	√	√	X	√
CCO	√	√	X	√
FED	√	X	√	√
PH	√	X	X	√
PS	√	X	X	√
CE	√	√	√	X
DPO	√	√	√	√

A, D = Less than successful projects
B, C = Successful projects
√= detected, X = No detection
Red = EWI did triggered problems, Green = did not triggered any problem

Furthermore, the implementation of case analysis framework concluded that there exist a direct relationship between "early warnings and project problems" and between "project problems and project performance," implying a relationship between early warnings and project performance. The major problems associated with each early warning that contributed to cost and schedule overrun are comprehended in following section.

Problems associated with NCO & CCO

- Out of sequence activity execution bring inefficiency
- Rework due to due to changes (direct impact on targeted activities and indirect impact on associated activities)
- Mismanagement of changes
- Subcontractor and vendor claims of schedule and cost
- Violation of baseline estimate (cost and schedule)

Problems associated with PH & PS

- Delay in critical information to downstream disciplines, procurement activities

- Inefficiency due to out of sequence execution
- Concurrent engineering execution

Problems associated with CE

- Possibility of assumed data changing at later stage, thus resulting into rework
- Delay in critical project milestones such as intermediate model reviews, final bulk quantity estimations
- Delay in Issuance of mechanical contracts for fabrication and construction

Problems associated with DPO

- Delay in vendor design information,
- Delay in issuance of final deliverables to fabrication and construction.
- Lack of work front for construction sub contractors resulting into idle cost

5. Quantitative analysis

In line with the research question underlying this research, the emphasis in quantitative analysis phase was to establish a quantitative relationship between early warnings and project performance. As explained in section 2, it is not possible to include qualitative early warnings (PES, COC and PTE) in development of the quantitative prediction model without introducing user specific subjectivity. In addition, the early warning, FED could not be incorporated, as it is static in nature and provides information only at the start of EPC phase.

5.1 Data collection

The data from past eight projects had been collected at 8 moments in EPC phase of each project. The data collected at start of engineering phase corresponds to the baseline values. Thereafter, the data was collected at every 15 % progress in engineering until 95 % engineering completion. The value at completion of the project represents the final project outcomes and determines the final performance of the project.

5.2 Quantitative analysis approach

On the basis of past project projects, three levels of exploratory investigation were carried out

- Behavioral analysis over engineering duration of the project
- Correlation analysis at effective engineering completion

The first level of analysis investigated the behavioral analysis of early warnings over engineering duration to investigate, if there exist a different behavior of EWI in good and less than successful performance projects. The second level of analysis investigates the correlations of EWI with project outcomes at 95% engineering completion. The objective of this analysis is to have a quantitative evidence of relationship between EWI and project outcomes.

5.3 Results

a) Results on behavioral analysis:

By analyzing the behavior of EWI over engineering duration, it was found that the early warnings do behave differently; however, their visibility is not uniform over all EWI.

The early (until 45-60% engineering completion) and continuous delay in process engineering was observed in less than successful projects. Whereas in successful projects the continuity of delay was not observed neither any significant early delays. The above insight imply towards the criticality of early process deliverables

In projects with of less than successful performance, process engineering forecasted significant growth in their hours (on average 25%) from 15% to 45% engineering completion, this phenomenon was not observed in successful projects.

A high numbers of incremental changes were observed in projects with less than successful performance. In addition, the time of high numbers of incremental changes does affect the severity of cost and schedule over run. It was observed that the projects in which high incremental changes were implemented late (after

45% engineering completion) they experienced more severe overruns.

Almost all the projects did experience increase in concurrency until 45% engineering completion, however less than successful projects did experience positive change (piping projecting schedule delay) of more than 30% in concurrency between 45% and 75% engineering completion.

5.b) Results of correlation analysis at effective engineering completion

The results of the correlation analysis are shown below:

Early warning indicator	Project outcome			
	ESI	MCI	MHI	TIC
CCO				++
CE			++	
DPO			++++	+++
NCO	+++	+++	+	
PH	+++	++++	+	++
PS	++		++++	+++

"++++" significant at 0.01 level, "+++" significant at 0.05 level, "++" significant at 0.1 level, "*" significant at 0.15 level, N = 8

Growth in process engineering (PH) is highly correlated with three project outcomes (ESI, MCI and TIC) and moderately correlated with MHI. The delay in the process engineering is highly correlated with ESI, MHI and TIC.

The numbers of change orders was found to be strongly correlated with schedule outcomes i.e. ESI and MCI and less correlated with cost outcomes. Where as the other aspect of change orders COC found to be highly correlated with project outcomes related to cost i.e. TIC.

The EWI, Delay in purchase orders is highly correlated with cost project outcomes (TIC and MHI). The possible conclusion can be drawn here that if issuance of purchase orders is delayed, then extra engineering manhours are required to process the delayed vendor information, thus results in growth of engineering manhours. Another possible conclusion could be that due to delay in issuance of purchase orders, projects do place costly orders, thus results into cost overrun, However there is no sound evidence was found, which support this conclusion.

The last EWI, change in concurrency is correlated with growth in engineering manhours. Which is found to be as per our hypothesis, because in case the piping engineering worked on assumptions (negative change in concurrency) during early engineering, Then there are chances that the assumptions might turned to be wrong or modified, which results in rework and delayed piping progress (positive change in concurrency).

5.d) Overall quantitative results

The result of quantitative analysis is summarized as follows:

1) Early warnings do behave differently in case of less than successful and successful projects, few in terms of their absolute value and few in their incremental changes.
2) Correlations do exist between EWI and project outcomes, however not all the EWI found to be correlated with all project outcomes.

The above results in combination with case studies do validate the predictive capability of EWI. However, it is very important to remember that the quantitative analysis was performed on very limited data set i.e. eight projects. Therefore, to have more concrete conclusion and evidence, more data would be required.

6. Prediction model

6.1 Development approach

The aim is to predict the final performance at early stages in the project, for the reason that in case of undesired performance, the project team should have the time and resources to act proactively and take corrective action without causing schedule or cost overrun. Another important aspect is that based on applied corrective action, what change has occurred in performance should be visible i.e. the prediction model should be a time-dependent dynamic model. The prediction moments are selected as same as section 5.1 (due to data availability at each moment)

Regarding the selection of predictive technique, the field of predictive analytics offers a verity of techniques from statistics, data modeling, and machine learning that can analyze historical facts to make predictions about the future performance of projects. However, due to the amount of available data and conceptual stage of the research, the techniques that can explain their reasoning of prediction are preferred. Based one the preliminary screening, the linear multi regression models seemed to be reasonable choice. They are simple and often provide an adequate and interpretable description of relationship between inputs and outputs. (Hastie et al. 2008)

The stepwise approach was adopted to develop the prediction model. At each prediction moments, the first step is to establish the correlations between EWI and project outcomes. Based on the analysis of the correlations, the EWI with at least moderate correlations (rs = 0.5) and 85 % probability (p=0.15) with project outcomes will be selected.

In the second step, the selected EWI were checked for multicollinearity i.e. the correlations among selected EWI. The aim was to select EWI, which were more independent and highly correlated with a project outcome. The criteria for multicollinearity is set at minimum rs = 0.7 and p = 0.05. This criterion is selected after a round of investigation into inter-correlation between EWI.

After the check for multicollinearity, independent and significant EWI were used for multi regression to predict the final project outcomes. The minimum requirement for EWI was set at two and due to the less numbers of past projects; the maximum limit for EWI in a regression model was limited to four (due to limited dataset). Therefore, in case of more than four EWI, the EWI were selected based on their regression coefficients i.e. the top four EWI with highest correlations with a project outcome were used.

6.1 Analysis of predictions

The data from past projects (as section 5 and 6.1) was used and forecast of final project performance were made using the prediction models developed from approach in section 6.1.

The analysis of predictions is done at two levels, comparison of forecasts made by prediction models with traditional forecasting methods and analysis of errors with actual outcomes of the projects.

The results of comparison between traditional method and prediction models are shown in table 4.

"+" sign means that the absolute error made by traditional methods is larger than the absolute error by prediction model, implying forecast made by prediction model is more accurate.

"-" sign means that the absolute error made by traditional methods is smaller than the absolute error by prediction model, implying forecast made by prediction model is less accurate.

Table 3: Comparison between forecast by traditional methods and prediction model

Prediction of project total cost								
Engineering completion	*Project Number*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
15%	+	+	+	+	+	-	+	+
30%	+	+	+	+	+	-	+	+
45%	+	+	+	+	+	-	+	+
60%	+	-	-	+	+	-	+	-
75%	+	-	+	+	+	+	+	-

Prediction of project schedule								
Engineering completion	*Project Number*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
15%	+	+	-	+	+	-	+	+
30%	+	+	-	-	+	-	+	+
45%	+	+	-	+	+	-	+	+
60%	+	-	-	-	+	-	+	+
75%	+	-	-	+	+	-	+	+

However, the analysis showed another limitation of dataset, bias towards less than successful performance projects. Therefore, to have a more accurate prediction in good projects, a dataset is required which contains a balance of good and less than successful performance projects.

For the second level analysis, errors between predicted and actual values of project outcomes cost and schedule were plotted over engineering duration of projects. The errors were measures in absolute terms irrespective of the sign.

The error found in prediction of project TIC is shown in figure 2, each curve represents an individual project. The curves reflects that for most of the projects, the error stays with in 6 % range till 45% engineering completion, Thereafter, absolute error go become as high as 12 % for few projects.

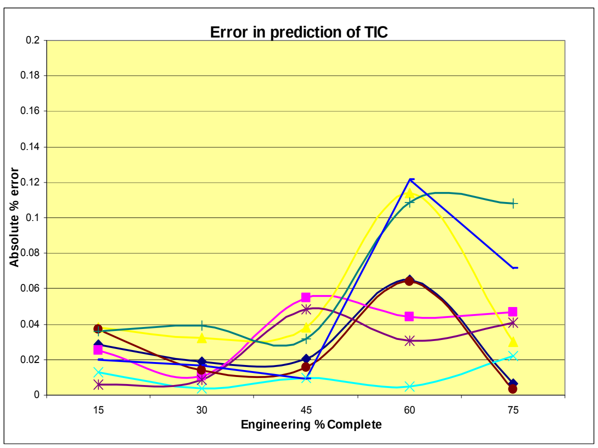


Figure 1 : Error in prediction of TIC

The schedule prediction of project, figure 3 shows the errors in prediction of MCI, it can be observed that on overall level, the errors seem to be decreasing from 30 % onwards. In addition, the error stays within 4 % ranges (except one project) in prediction after the completion of 45 % engineering.

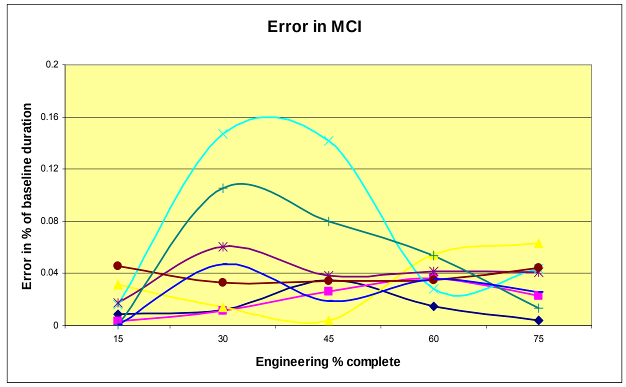


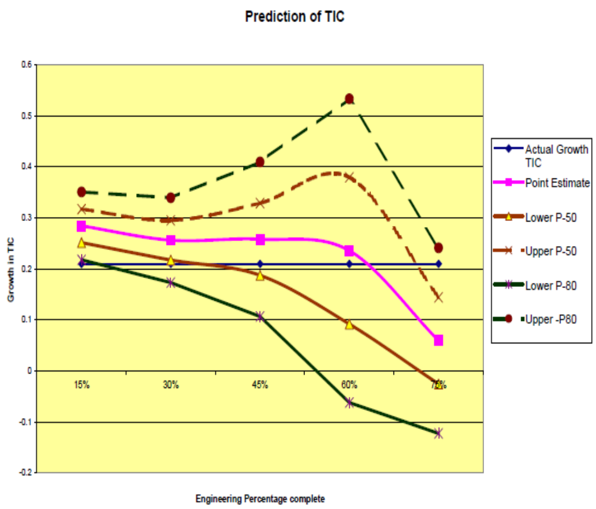
Figure 2: Error in prediction of MCI

Based upon the findings in this section, it should be concluded that the accuracy level of prediction model developed by this research need more preciseness and validation. To have more preciseness, a larger dataset with balance of good and less than successful performance project is required. Nonetheless, it can be concluded that if the approach developed by this research is applied to a larger and rich dataset, a more precise and better prediction model could be developed.

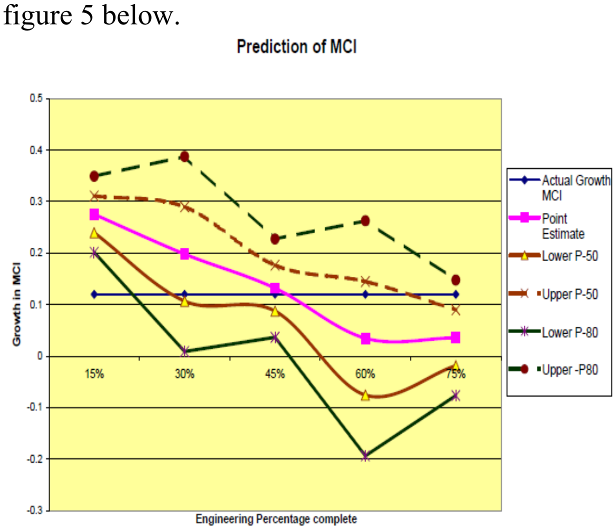
6.1 External validation

The external validation for model is performed by using data from an external project. The forecast of final project performance are made for each prediction moment. The predictions are made as "point estimate," prediction ranges with 50% confidence (P50) and with 80% confidence (P80). All predictions were plotted against actual project outcomes and results are discussed in following paragraphs.

The point prediction for growth in TIC was found to be in acceptable limit from 15% to 60% engineering completion. However, at 75% prediction the error was found to be quite high (16%). From 15 % to 60% engineering completion, the estimated ranges are quite reasonable as compared to actual value. Longitudinally, the estimates improve. However, at later stages, the lower bound values show a possibility of under run. In case of P80, the average difference between the ranges is too wide (± 15.5 %), therefore considered as less reliable. The results are shown in figure 4 below:



The validation results for MCI are shown in following figure. The point estimate did improve longitudinally, but showed a less growth at 75% engineering completion. The actual value is more or less within P50 range. The prediction does seem to improve longitudinally. However goes below the actual value after 45% engineering completion and predict a lower growth at 60% and 75% engineering completion. Te results are shown in figure 5 below.



The results of external validation reflected the limited reliability and accuracy of pilot. On average, the point predictions of project outcomes, however lacks consistent behavior. The prediction ranges with 50% confidence (P50) embrace the actual value and could be seen as reasonable prediction ranges. The prediction ranges with 80% confidence interval were found to be too wide and in current state could not be used for guiding the decision-making.

7. Overall discussion

The present research focuses on the management of problems before they affect the project execution. In other words, marking a shift in the attention of project management from "manage what has happened" to "manage what will happen." The presented approach could provide the opportunity for project managers to act well in advance incase the early warnings predict an undesired performance.

Based on so far research it can be concluded that early warnings can be used for predicting the future performance of the project. In addition, specific potential future problems associated with early warnings could also be known before they affect the project performance. However, the above answer to main research question is partial in nature due to very limited dataset used in this research, therefore limits the generalization of findings.

To have more concrete conclusions and better prediction model, a larger dataset consisting of more projects with similar nature should be used. The findings and model development approach presented in this research can guide the development and validation of a reliable and accurate model. Furthermore, in future the model could be converted into operational prediction system with sophisticated platform and technical architecture based on this research.

In terms of contribution, the research possibly has following main contributions to scientific and industry.

Contribution to scientific community

- An approach to improve upon current project control techniques and marking a shift from reactive project management to proactive project management
- An introduction and approach to implement prediction modeling for better management of project execution

Contribution to O&C project industry

- An approach, which facilitate the early detection of future potential problems
- An approach to capitalize on past projects to improve project performance management

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