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A framework to improve performance measurement in engineering projects

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***Abstract*:** A wide range of methods and good practices have been developed for the measurement of projects performance. They help project managers to effectively monitor the project progress and evaluate results. However, from a literature review, we noticed several remaining critical issues in measuring projects performance, such as an unbalanced development of Key Performance Indicators types between lagging and leading indicators. On the other hand, systems engineering measurement is a more recent discipline with practices and theories that appeared with the emergence of the systems engineering discipline; however, this discipline offers very deep developments, published in several standards and guides. In particular, systems engineering measurement does not only manipulate lagging indicators, useful to track how things are going, but defines methods to promote leading indicators, used as precursors to the direction the engineering is going. Indeed, 18 leading indicators were recently proposed, validated, and finally engineered in a practical guidance. The objective of this paper being to improve project performance and success rate, one mean is to improve the measurement of projects performance by enriching its leading indicators, on which decisions rely on project management. To reach this goal, we propose to refine and extend the performance measurement activities in the Project Management Body of Knowledge (PMBoK version 5) by considering systems engineering measurement. This paper thus considers transferring and adapting the good practices in systems engineering measurement such as described in systems engineering guides as well as the set of systems engineering leading indicators to the well-defined project management processes in PMBoK. To this effect, we propose a methodology resulting in a framework to explore this integration. This way, systems engineering leading indicators can be applied to project performance measurement, thus providing project managers with a wider set of leading indicators and straightforward measurement techniques.

Keywords: projects performance; systems engineering measurement; leading indicators; lagging indicators;

1. Introduction

In the PMBoK, measurement of project performance is thought as an assessment about the magnitude of variation from the original scope baseline. Project performance measurement is receiving wide focus from both academy and practitioners and some remarking results have been achieved, such as earned value project management, performance measurement of engineering projects (Atkinson, 1999), or benchmarking project performance management. Even though these results have great contributions to the economic development and enterprise competitions, it seems that most studies are based on the outcome measurement of project performance with a wide variety of lagging indicators, used to track how things are going and be able to confirm that something is occurring or about to occur (Atkinson, 1999; Zidane et al., 2015). Relatively few studies focus on prediction-based measurement of project performance with leading indicators which are performance drivers and provide early warning information (Guo and Yiu, 2015; Kueng et al., 2001).

Conversely, systems engineering measurement is related to more recent practices and theories, which appeared with the emergence of the systems engineering discipline (Wilbur, 1995); however, systems engineering measurement offers very deep developments, published in several

standards and guides (Roedler et al., 2010; Wilbur, 1995). In particular, it is also important to note that systems engineering measurement does not only use lagging measurement but defines methods to promote leading measurement recently (Rhodes et al., 2009); therefore indeed, as a result, 18 leading indicators were recently proposed, validated, and finally engineered in a practical guidance (Roedler et al., 2010).

The purpose of this paper, therefore, is to broaden the path of project performance measurement through applying the systems engineering leading indicators to project performance measurement based on a mapping mechanism designed between the two disciplines.

2. Research background on project performance and systems engineering measurement

(1) Research background on the measurement of project performance

Generally, in the measurement of project performance (MPP), there are two types of indicators, which are lagging indicators and leading indicators. The characteristics of MPP evolution can be generated below:

- The history of MPP has largely experienced the lagging indicators, however the concept of leading indicators is not yet being used effectively.
- The most popular model for project management is Earned Value Management, however only limited leading indicators are available.
- Perspectives for MPP are variable, not developed systematically, and the description of leading indicators differs according to the opinions of researchers.

From the characteristics above, we can see that lagging indicators are widely used, but leading indicators are not. However, both types of indicators are important in providing project performance information. Thus we propose to build a balanced performance measurement system with leading and lagging indicators. To this respect, we learn some advanced measurement practices from other measurement practices, such as systems engineering measurement. Systems engineering measurement (SEM) is experiencing a remarking development with a shift from outcome measurement to predictive one, which has provided many available guides and standards for measurement, particularly its advance in leading indicators. A mapping of the measurement methods from SEM to MPP has been proposed in section 3. Based on the mapping, a further step has been defined to analyze the processes of transferring and adapting the good practices of SEM to "balance" the indicator types of MPP.

(2) Research background on systems engineering measurement

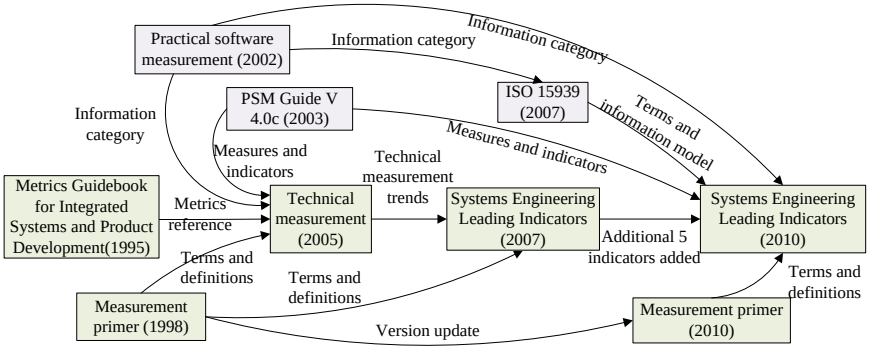

Figure 1 Overview on Systems Engineering Measurement Evolution

For effectively evaluating the health status of systems engineering in a program, many researchers and practitioners have provided some ideas for measuring and monitoring SE process (Xue et al., 2016). As a result, a series of formal guidebooks have been developed and published since 1995: Metrics Guidebook for Integrated Systems and Product Development

(Wilbur, 1995), INCOSE SE measurement primer (INCOSE Measurement Working Group, 2010), Technical Measurement (PSM and INCOSE, 2005), and Systems Engineering Leading Indicators (Roedler et al., 2010).

From the development and characteristics of systems engineering measurement (SEM), some of its advantages could be summarized as following:

- The history of systems engineering measurement has experienced from lagging indicators to the "balance" of lagging and leading indicators, and both lagging and leading indicators constitute a systemic, effective and balanced SEM.
- A set of systems engineering leading indicators (SELIs) are developed based on the practices of systems engineering, the leading indicators align well with pre-existing measurement references, and the specification (rationale, decision insight, measure and calculation) of leading indicators has been engineered.

This short comparison of the advantages of SEM development and the shortcomings of MPP leads to conclude that the application of SEM practices by introducing the SELIs in the project management can improve the dominance of lagging indicators in the MPP.

3. Proposal of a framework to improve project performance measurement

Considering the history and evolutions of both disciplines, we propose to transfer and adapt the good practices and indicators of systems engineering performance measurement to project performance measurement. To this respect, we consider the 18 leading indicators proposed by the INCOSE (Roedler et al., 2010) and Knowledge Area (KA) of the PMBoK to analyze if a mapping could be possible.

Each systems engineering leading indicator has its information category and leading insights. The information category specifies what categories are applicable for this leading indicator. The leading insights specify what specific insights the leading indicator may provide. Each Knowledge Area of PMBoK offers a set of processes, and each one of these process includes a list of inputs, tools and techniques, and outputs, from which information needs can be derived.

To make a mapping we proceed in two steps. First step consists in verifying whether systems engineering leading indicators can be usefully associated to Knowledge Areas. We take each SELI and evaluate its interest (analyzing the information category and leading insights) for each KA. This analysis results in a framework establishing a list of SELIs that can be associated to each KA to improve project performance measurement (see Table 1).

Table 1 The mapping of systems engineering leading indicators per knowledge area of PMBoK 5

18 systems engineering leading indicators \ 10 Knowledge Areas of PMBoK 5	Project Integration Management	Project Scope Management	Project Time Management	Project Cost Management	Project Quality Management	Project Human Resource Management	Project Communication Management	Project Risk Management	Project Procurement Management	Project Stakeholder Management
Requirements trends		X			X					
System definition change backlog trend	X	X	X		X					
Interface trends		X								
Requirements validation trends		X			X					
Requirements verification trends		X			X					
Work product approval trends			X		X		X			
Review action closure trends			X		X					X
Technology maturity trends		X								
Risk exposure trends			X	X	X	X		X		
Risk treatment trends			X		X			X		
Systems engineering staffing & skills trends				X		X				
Process compliance trends										

Technical measurement trends		X			X					
Facility and equipment availability trends			X	X						
Defect/ error trends					X					
System affordability trends			X	X				X		
Architecture trends					X					X
Schedule and cost pressure			X	X				X		

A second step consists in deepening the analysis by focusing on each Knowledge Area, by turn, in order to integrate each SELI identified in the list of useful indicators to this KA (cf first step) with the processes of the KA.

For example, we look at the project quality management knowledge area from Table 1, there are 11 SELIs mapped to it. But the assumed information needs here is the quality of documentation. So the leading indicator--defect and error trend can be chosen to monitor the quality of documentation by tracking the defects of it. Once the SELI is chosen, we should further tailor it to satisfy the current project context. The tailored indicator includes: a base measure—number of defects found at each discovery stage, a derived measure--estimated number of latent defects, thresholds and outliers—range of acceptable values for defect discovery based on past project history. A defect discovery profile can thus be built based on the tailored indicator.

4. Conclusion

This paper addresses the measurement of engineering project performance and its balanced utilization between lagging and leading indicators to ensure the project in a healthy status. It provides a framework that associates leading indicators used in systems engineering with the project management processes described in the PMBoK knowledge areas. This contributed to improve performance measurement in engineering projects, thus resulting in a better monitoring and finally a better performance of these projects.

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