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## Considering the systems engineering leading indicators to measure projects performance

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**Abstract** *To measure projects performance is available a wide range of methods which help project managers to effectively control the project progress and evaluate project results (Atkinson, 1999; Anantatmula, 2015). However remain several critical issues in their application: unbalanced development of KPIs types (Zidane, Johansen and Ekambaram, 2015), limited availability of leading KPIs (Kueng, Andres, and Wettstein, 2001), etc. Conversely, even if systems engineering measurement (SEM) is a more recent discipline, it offers very deep developments, published in several standards and guides (Wilbur, 1995; INCOSE Measurement Working Group, 1998; INCOSE Measurement Working Group, 2010; INCOSE & PSM, 2005; Roedler, et al., 2010). In particular, SEM uses lagging (reactive) measurement and defines methods to promote leading (predictive) measurement which provides insights before a problem arises (INCOSE & PSM, 2005; Roedler, et al., 2010).*

*To improve project success rate, we propose to improve the measurement of projects performance, on which decisions rely in project management. One way is to extend the indicators to measure project performance by indicators used to measure systems engineering performance. This paper thus considers transferring and adapting the good practices in SE performance measurement such as described in SE guides as well as the set of SE leading indicators (SELIs) defined in (Roedler, et al., 2010) to project performance measurement.*

### INTRODUCTION

(BARC, 2009) is a global survey that explores the key challenges faced by organizations today and it is pointed that these challenges make performance management become a key enabler. In fact, since the early 1980s, performance management in general has been widely developed for adapting enterprises into complex business environment through introducing non-financial indicators. Some typical and classic PMSs have been proposed between 1980s and the 1990s, like the Performance Pyramid System (Lynch and Cross 1991) or the Balanced Scorecard (Kaplan and Norton 1992, 1996). Since, the family of PMSs grew with experts from different disciplines having brought fresh blood in the domain by blending the methods of system dynamic, total quality management, supply chain management and so on into the traditional PMSs. As one related diversification, the measurement of projects performance (MPP) has been

receiving wide focus from both academy and practitioners (Lauras, Marques and Gourc, 2010; Zheng, et al., 2016). Focus has been diversified in many domains and some remarking results have been gotten, such as earned value project management (Anbari, 2003; Lipke, et al., 2009), performance measurement of engineering projects (Shi., et al., 2015; Guo and Yiu, 2015), benchmarking project performance management (Barber, 2014; Kim and Huynh, 2008 ), et al.

Even through the research results have great contributions to the economic development and enterprise competitions, but it seems that all the prior MPP research has proposed a wide variety of KPIs or measures that evaluate the outcomes of a project based on the traditional “iron triangle”: “cost, time and quality” (Atkinson, 1999; Zidane, Johansen and Ekambaram, 2015). Some research provided a set of KPIs that can monitor and control project progress in time and set alarms whenever deviations of project

processes are observed (Anderson and McAdam, 2004; Luu, Kim and Huynh, 2008; Kakar and Thompson, 2010). Over the years, a leading measurement for project management has been proposed, and several approaches have been developed for this kind of active measurement. One of these approaches is earned value project management (EVPM) which has been identified as an efficient tool for cost and schedule prediction (Anbari, 2003; Lipke, et al., 2009; Fleming and Koppelman, 2006). Based on the main principles of EVPM, considerable research on the extensions and applications of EVPM were published (Pajares and López-Paredes, 2011; Turkan et al., 2013; Chen, Chen & Lin, 2016). However, both the traditional EVPM research and studies on extensions and applications of EVPM concentrate on cost and time rather than other important performance measures like customer satisfactions, team performance and so on, which couldn't apt for the more complex projects in challenging environments.

In order to improve the limited indicators of EVPM for leading measurement, some researchers have proposed a web-based project performance monitoring system which can provide project managers timely signaling of project problems (Cheung, Suen and Cheung, 2004). Automated data collection (ADC) technologies have been developed to provide powerful tools for measuring the status of project life cycle (Navon, 2007). Obviously, the "leading" systems have not gotten much attention or application. Leading indicators for MPP have not been implemented to a substantial degree. Conversely, systems engineering measurement (SEM) is related to more recent practices and theories, which appeared with the emergence of the systems engineering discipline (Wilbur, 1995); however SEM offers very deep developments, published in several standards and guides (Wilbur, 1995; INCOSE Measurement Working Group, 1998; INCOSE Measurement Working Group, 2010; INCOSE & PSM, 2005; Roedler, et al., 2010). In particular, It is also important to note that SEM does not only use lagging measurement but defines methods to promote to leading measurement (Rhodes, Valerdi and Roedler, 2009) recently; 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 the current paper is to apply the SE leading indicators to MPP by a mapping

mechanism designed between the two disciplines. A case study could demonstrate it.

Next two sections A and B review literature in MPP and SEM. Section C presents a proposal of mapping mechanism transferring SELIs into MPP. The last section concludes on the achievement of our research objectives and gives perspectives about further research.

## A. LITERATURE REVIEW IN MPP

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Three strategies exist to measure projects performance: ex-post evaluation, in-progress and leading measurement.

### (1) Ex-post evaluation

This strategy aims at answering questions like "Did we do it right?" and "Did we get it right?" Over the last 70 years, the Iron Triangle- cost, time and quality have been regarded as the cornerstone of evaluating whether a project has been a success or a failure. With economic globalization, virtual organizations, great competition and environmental focus, many traditional theories have been challenged and showed their limits in practices for obtaining success. Atkinson (1999) has proposed a new framework to suggests the Iron Triangle could be developed to become the Square-Route of success criteria including not only "cost, time and quality" but also the information system, benefits of organization and benefits of stakeholder community. Some scholars proposed the model of extracting automatically KPIs (Key Performance Indicators) from the data in real time in the collaborative engineering projects, which thought that predefined indicators are not always sufficient to handle all possible situations (Shi et al., 2015). Measurement researches and practitioner activities for project management are around post-project success evaluations, in which measurement is deployed from project efficiency (focus on iron-triangle), project effectiveness (focus on the objective obtainment) and so on. (Zidane, Johansen and Ekambaram, 2015) have proposed a holistic framework for project evaluation, in which Project efficiency, Effectiveness, Impacts, Relevance and sustainability are considered at the same time and all elements and interdependencies are showed. This type of MPP has two main drawbacks: 1) no real time control, 2) measures tend to be lagging.

### (2) In-progress measurement

Considering the above drawbacks, this strategy

consists in addressing questions like “Do we do it right?” and “Do we get it right?” Thus, some efficient methods like benchmarking have been proposed to monitoring the progress measurement of projects performance (Luu, Kim and Huynh, 2008). The use of benchmarking should be extended beyond the comparison of lagging indicators (Anderson and McAdam, 2004). But benchmarking has its drawbacks reflected by projects, and it cannot address problems that have not been previously recognized or encountered (Barber, 2004). Automated Data Collection (ADC) technologies have provided powerful tools for measuring the status of project life cycle (Navon, 2007). It also was proposed that the use of a combined Balanced Scorecard and Stage-gate framework is likely to provide more effective project governance in project life cycle though providing key support for decision-making gates (Kakar and Thompson, 2010). But with it, there are still some problems: 1) no risk prediction; 2) no alarm reminding.

### (3) Leading measurement

Over the years, people start trying using multidisciplinary approaches to answer questions like “Will we do it right?” and “Will we get it right?” Leading measurement is a kind of active measurement. Earned value project management (EVPM) has provided methods for predicting the final cost for projects (Anbari, 2003; Lipke, et al., 2009). A project manager could benefit from receiving an early warning cost signal in time to alter the ultimate direction of a project (Fleming and Koppelman, 2006). Based on the main thoughts of EVPM, considerable research on the extensions and applications of EVPM are published, for example, some scholars have proposed to improve the use of planned value (Chen, Chen, and Lin; 2016); others have integrated EVPM and Project Risk management methodologies (Pajares & Lopez-Paredes, 2011). EVPM has become an important component of successful project management by helping monitor and predict project performance. It shows that EVPM outcome prediction for cost is reasonably reliable for the measurement of projects performance, but it is striking that all related EVPM researches are geared towards cost and schedule measures. Other level consideration such as quality improvement, customer satisfaction or project team members’ performance cannot be predicted. However all the factors could lead certain risk for

project completion? A web-based project performance monitoring system has been developed to provide project managers timely signaling of project problems (Cheung, Suen and Cheung, 2004). We can find that in these MPPs it includes not only financial aspects but also covers soft parameters. Some researchers have proposed multi-dimensional measurement of projects performance system, in which nine essential knowledge and management areas to describe project management of Project Management Body of Knowledge (PMI Standards Committee, 2013) are suggested to 9 characters in consideration that areas covered by performance management must be as complete as possible (Marques, Gourc, and Lauras, 2011). Even though the realization to extend the leading indicators in project management seems to have passed project management by in both the literature and many instances of practice (Marques, Gourc, and Lauras, 2011; Cheung, Suen and Cheung, 2004), but evidently not enough results operational are inside the availability.

From this development of MPP based on the three strategies above, lagging indicators are still in a dominant place and receive the most attention; however leading indicators do not find their way to implementation and proper use (Kuong, Andres, and Wettstein, 2001). The shortcomings of MPP approaches are analysed as following:

- The history of MPP has experienced from lagging indicators to current indicators; the concept of leading indicators is not yet being used effectively;
- The most popular model for project management is EVM, however only limited indicators are calculated and predicted;
- Perspectives for MPP are variable, not developed systematically, the design-implement-run process of leading indicators KPIs differs according to the opinions of researchers;
- MPP has wide backgrounds, but no engineered standards are abstracted.

However, systems engineering, as one of its related disciplines, is experiencing the remarking development with a shift from lagging measurement to leading driving, which has provided many available guides and standards for measurement, particularly for leading measurement. A trial to mapping the measurement methods of SE to the MPP has been proposed.

## B. LITERATURE REVIEW IN SEM

The thought of systems engineering metrics has been a concept since a long history, many researchers and practitioners have provided some ideas for measuring and monitoring SE process (Kasser, 1994). However, 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, 1998; INCOSE Measurement Working Group, 2010), Technical Measurement (INCOSE & PSM, 2005), and Systems engineering Leading Indicators (Roedler, et al., 2010) respectively. In our literature review, only directly SE-related measurement guidebooks are chosen. In fact the guidebooks are based on different other standards and guidebooks from other domains, typically like software engineering. Particularly, SE leading indicators (Roedler, et al., 2010) result from efforts of different organizations, which are developed and published by LAI (Lean Advancement Initiative), INCOSE (International Council on Systems Engineering), SEArI (Systems Engineering Advancement Research Initiative) & PSM (Practical Systems and Software Measurement). Metrics Guidebook for Integrated Systems and Product Development which is the first formal guide for systems engineering measurement published in 1995 has been prepared for supporting systems engineering program measurement. In this guide, thousands of metrics were collected, categorized, and assessed as candidates; it supports group establishing new metrics program. However, there are some drawbacks about this guide book, 1) it presented only lagging indicators; 2) no detailed guide about how to aggregate the data collected with models or functions.

Then, INCOSE SE measurement primer version 1.0 (INCOSE Measurement Working Group, 1998) was published with two objectives: 1) define the basic concepts behind measurement and measurement programs; 2) provide requisite background knowledge. To reflect the change in ISO and PSM guidance, it has been revised to version 2.0 (INCOSE Measurement Working Group, 2010). However it has only synthesized key guiding principles consistent with the ISO/IEC 15939:2007 Systems and software engineering—Measurement process and the Practical Software and Systems Measurement (PSM) guidebook,

no information about how to realize a construct of a SE leading indicators (Rhodes, Valerdi and Roedler, 2009).

Technical measurement, version 1.0 (PSM & INCOSE, 2005) developed collaboratively by PSM, INCOSE, and Industry, is a set of measurement activities used to provide the stakeholders insight into progress in the definition and development of the technical solution. It presents the ongoing assessment, mainly for risks and issues associated with technical aspects.

These three guidebooks have been applied in SE practical activities and get general recognition; however, all these are still staying in lagging measurement and the ongoing measurement, as to how to predict potential risks and issues has only been referred as a concept.

In the early 21st century, for solving such problems, the INCOSE organization collaborated with others, having published systems engineering leading indicators guidance, version 1.0 (Roedler and Rhodes, 2007) with defining thirteen indicators, and then has been extended to 18 indicators (Roedler, et al., 2010). These are measures for evaluating the effectiveness of the systems engineering activities on a program in a manner that provides information about impacts that are likely to affect the system or program performance objectives (Roedler, et al., 2010). Such measurement practices have brought SE measurement stepping into a new milestone—shift from lagging measurement to leading one. From figure 1, the systems engineering leading indicators are aligned with pre-existing guidebooks and related measurement standards and practices in other disciplines (Rhodes, Valerdi and Roedler, 2009). Leading indicators at first glance may appear similar to existing measures and often use the same base information, the difference lies in how the information is gathered, evaluated, interpreted and used to provide a forward looking perspective (Rhodes, Valerdi and Roedler, 2009).

From the development of SEM, some results have been found, which fit well for the shortcomings proposed above in the MPP:

- The history of systems engineering measurement has experienced from lagging indicators to leading indicators, and leading indicators align well with pre-existing measurement references;
- Large number of leading indicators are developed in practices of systems engineering;

- The design-implement-run process of leading indicators nearly has been engineered, and leading indicators for SEPM were developed systematically and planned and designed carefully;
- They make full use of engineering project/program practices and experiences for abstracting practical guidebooks.

Such a kind of correspondence in those two disciplines brings further light on the proposal of this research: mapping the leading indicators in systems engineering into the practices of MPP

### C. THE MAPPING OF SE LEADING INDICATORS IN THE MPP

Many researches focus on the integration of processes in SE and PM. SE management always uses some subsets of PM methods and tools (Sharon, 2010). But little have tried to put the methods of SE measurement into project management. With consideration of the history and evolutions of both disciplines, we propose to transfer and adapt the good practices about SE performance measurement to project management.

#### 1. Insights provided by SE leading indicators and project management knowledge areas

Insights provided by SE leading indicators and Project management knowledge areas and its processes have been chosen as the research objective. 18 leading indicators were identified through the efforts of SE experts. Not only are these indicators for systems engineering, but they are most likely indicators of overall project performance and health (Roedler, et al., 2010). A Guide to the Project Management Body of Knowledge (PMBoK Guide) is a guidance that presents a set of standard terminology and guidelines for project management. Since its first publication in 1996 by the Project Management Institute (PMI), it has received a consensus about their value and usefulness. In 2013, the fifth edition was released (PMI, 2013). For its general recognition and good practice in varied domains, its 47 project management processes in the 10 knowledge areas are chosen as the mapping base in this research (see table 3 in appendix).

#### 2. The mapping mechanism

SE and PM are different disciplines. For better integration and application of SE leading indicators to

the project management processes, a referred mapping mechanism has been proposed in this research (figure 1). In the mechanism, four steps are proposed: “read through”, “specify”, “tailor”, and “apply” respectively.

Read through: every leading indicator has variable insights with different base measures. Each insight plays the role to give information about utilization benefit. Each process in each knowledge area of PMBoK (PMBoK 2013) has objectives to achieve. The principle to map is that if at least one insight fits well for the objectives to achieve, the leading indicator will be chosen as candidate indicator for the knowledge area. Generally, one leading indicator cycles 10 times for 10 knowledge areas by the step “read through” to find its available application in the 10 knowledge areas.

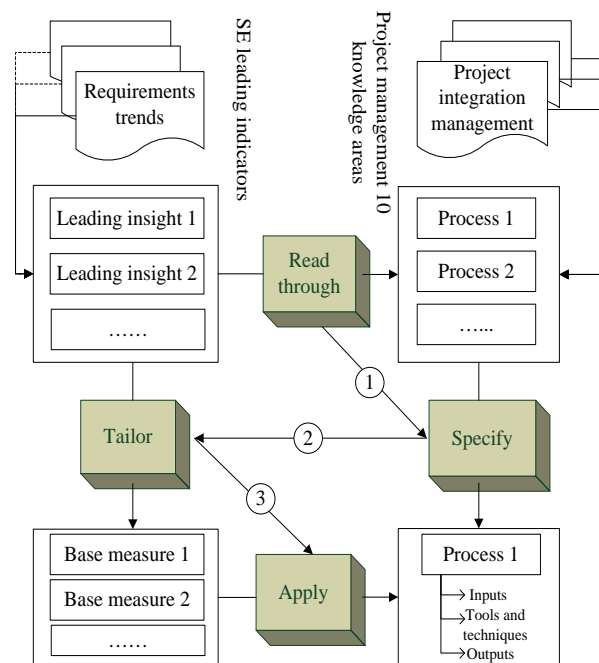


Figure 1 A mapping mechanism for applying SE leading indicators in the project processes

Specify: once one indicator finds its “fitting point” in certain process of certain knowledge area, it’s necessary to specify project backgrounds, and look through the detailed data flow in one process—inputs, technique and tools, and outputs to set the indicator in its appropriate position.

Tailor: this step is necessary for two reasons—the nature of each leading indicator and project backgrounds. The nature of each leading indicator is unique. It includes several base measures and derived measures; nevertheless, not every project needs all these. Once the project background is specified, focus

returns to the insights and its base measures for verifying and choosing appropriate base measures and measurement functions.

Apply: after tailoring, for better application, it's necessary to do a mapping matrix analysis for finding positions for the tailored base measures; and then based on different knowledge areas and their specific project processes, derived leading indicators for specific project could be abstracted. Integration with existing KPIs should be also considered in this step.

In this research, a case study conducted in a manufacturing company verified that the application of the mapping mechanism could improve the performance of a project and help identify some derived leading indicators based on the specific project background.

## CONCLUSION

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This paper explored the proposal of applying SE leading indicators to improve the measurement of projects performance. First, we reviewed literature in the domain of the measurement of projects performance and systems engineering measurement. It seemed that the measurement of projects performance varies and focuses much on ex-post evaluation based on traditional "iron-triangle", while no many leading indicators are available; conversely, systems engineering measurement offers very deep developments, published in several standards and guides, and it does not only use lagging measurement

but defines methods to promote to leading measurement. Thus, a trial of applying the SE leading indicators into the measurement of projects performance was proposed. We elaborated a "4-steps" mapping mechanism ensuring that the cross-disciplinary application could follow an appropriate rule. This mechanism includes "read through", "specify", "tailor", and "apply". Reading through both sights provided by certain SE leading indicator and objectives described in the 10 knowledges of PMBoK catches a sight whether certain SE leading indicator could be used for the processes of certain knowledge area. Specifying the specific project background with the data flow in each process of project management knowledge area provides the basis of tailoring the SE leading indicator. Tailoring the base measures and measurement function in the guidance fits well for a specific project. Applying the tailored base measures and measurement function to the data flows in the processes of project management knowledge shows that the appropriate position could be found. A case study conducted in a manufacturing company confirmed that the application of leading indicators in SEM could integrate well with existing project measurement activities and help the project team to effectively control the performance of project quality management. However, a quantitative validation now needs to be done.

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