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# What to Measure for Success in Lean System Engineering Programs?

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**Abstract.** The system engineering literature acknowledges that lean principles foster the achievement of higher program performance. However in the literature it is not clear how exactly the six lean principles affect the performance of the systems engineering programs. This paper addresses this gap by discussing about the core benefits derived from the implementation of each lean principle. Main contribution of this paper is the proposal –through a deep literature investigation refined through a series of focus groups with the Lean in Program Management Community of Practice (MIT-PMI-INCOSE) – of a list of metrics to be considered in order to measure the performance affected by the introduction of a list of 43 Lean Enablers. Only when measuring the current situation of the systems engineering program in fact, it is possible to direct improvement efforts. Further steps of authors' research are direct to understand how the collected metrics could practically and effectively support the lean journey within system engineering programs.



Keywords: Performance Measurement System; System Engineering; Lean Thinking.

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## 1. Introduction

The lean thinking approach banishes waste and creates wealth in organization [1]. The system engineering literature acknowledges that lean principles foster the achievement of higher program performance. Indeed these benefits are because lean focuses both on the customer, highlighting the importance of understanding what are the customer's needs, and on the empowerment of the engineering team. The pillar of lean is the adoption of its six principles – value, value stream, flow, pull, perfection, and respect for people – which can be accomplished by the implementation of group of best practices called lean enablers. The implementation of these enablers ensures the achievement of the mentioned benefits. However in the literature it is not clear how exactly the lean principles affect the performance of the systems engineering programs.

This work addresses this research gap by providing a deeply comprehension about what are the core benefits derived from the implementation of each lean principle. Moreover it proposes a list of relevant key performance metrics, mapped against the lean enablers, and correlated to the lean principles.

An extensive literature review were performed first to gather evidence of the lean principle benefits, and second to collect the key performance indicators used in engineering programs. Afterward focus group discussions were conducted to map the indicators against the lean enablers and the lean principles. The validation is still in progress within the MIT-PMI-INCOSE Community of Practice.

The in deep discussion about how the lean principles improve the program performance provides a new insight on the system engineering literature field. The traditional metrics are strongly criticized by academics and practitioners to be mainly financial and/or account oriented and not suitable to measure engineering programs. Therefore, the practitioners can benefit from the list of metrics provided here, which is lean oriented. The organization implementing the lean principles can use the mapping in order to identify which metrics should be tracked to insure the effectiveness of the implementation. Finally, the map of metrics versus lean enablers can be a useful tool for companies still not sure where to start their lean journey. The map assists with the identification of the areas related to the worst performance, and with the choice of which lean enablers to implement first.

## 2. Lean engineering programs: the Lean Enablers and lean metrics

Nowadays achieving excellence in product development is considered one of the top strategic differentiators, even more than manufacturing capability. This change relies on the fact that developing new products faster than competitors do is an effective strategic weapon to succeed in increasingly turbulent markets.

Though, manage systems engineering programs successfully is highly challenging. Literature [2] reports about 10 main challenges affecting systems engineering program management: (i) firefighting -reactive program execution-, (ii) unstable, unclear, and incomplete requirements, (iii) insufficient alignment and coordination of the extended enterprise, (iv) processes are locally optimized and not integrated for the entire enterprise, (v) unclear roles, responsibilities, and accountability, (vi) mismanagement of program culture, team competency, and knowledge, (vii) insufficient program planning, (viii) improper metrics, metric systems, and KPIs, (ix) lack of proactive program risk management and (x) poor program acquisition and contracting practices.

Lean philosophy is considered to be very effective to overcome these criticalities. Liker [3] stated that Lean Product Development is a philosophy that integrates people, processes, tools and technology to add value to the customer.

Table 1. Lean Enablers.

| Lean Principle | Lean Enablers |
|---|---|
| Respect for People | 1.1 -Build a program culture based on respect for people |
| | 1.2 -Motivate by making the higher purpose of the program and program elements transparent |
| | 1.3 -Support an autonomous working style |
| | 1.4 -Expect and support people as they strive for professional excellence and promote their careers |
| | 1.5 -Promote the ability to rapidly learn and continuously improve |
| | 1.6 -Encourage personal networks and interactions |
| Value | 2.1 -Establish the value and benefit of the program to the stakeholders |
| | 2.2 -Focus all program activities on the benefits that the program intends to deliver |
| | 2.3 -Frequently engage the stakeholders throughout the program lifecycle |
| | 2.4 -Develop high-quality program requirements among customer stakeholders before bidding and execution process begins |
| | 2.5 -Clarify, derive and prioritize requirements early, often and proactively |
| | 2.6 -Actively minimize the bureaucratic, regulatory and compliance burden on the program and sub-projects |
| Value Stream | 3.1 -Map the management and engineering value streams and eliminate non-value added elements |
| | 3.2 -Actively Architect and manage the Program Enterprise to optimize its performance as a system |
| | 3.3 -Pursue multiple solution sets in parallel |
| | 3.4 -Ensure up-front that capabilities exist to deliver program requirements |
| | 3.5 -Front-load and integrate the program |
| | 3.6 -Use probabilistic estimates in program planning |
| | 3.7 -Work with suppliers to proactively avoid conflict and anticipate and mitigate program risk |
| | 3.8 -Plan leading indicators and metrics to manage the program |
| | 3.9 -Develop an Integrated Program Schedule at the level of detail for which you have dependable information |
| | 3.10 -Manage Technology Readiness Levels and protect program from Low-TRL delays and cost overruns |
| | 3.11 -Develop a Communications Plan |
| Flow | 4.1 -Use systems engineering to coordinate and integrate all engineering activities in the program |
| | 4.2 -Ensure clear responsibility, accountability and authority (RAA) throughout the program from initial requirements definition to final delivery |
| | 4.3 -For every program, use a program manager role to lead and integrate program from start to finish |
| | 4.4 -The top level program management (e.g., program management office) overseeing the program must be highly effective |
| | 4.5 -Pursue collaborative and inclusive decision making that resolves the root causes of issues |
| | 4.6 -Integrate all Program Elements and Functions through Program Governance |
| | 4.7 -Use efficient and effective communication and coordination with program team |
| | 4.8 -Standardize key program and project elements throughout the program to increase efficiency and facilitate collaboration |
| | 4.9 -Use Lean Thinking to promote smooth program flow |
| | 4.10 -Make program progress visible to all |
| Pull | 5.1 -Pull tasks and outputs based on need, and reject others as waste |
| | 5.2 -Establish effective contracting vehicles in the program that support the program in achieving the planned benefits and create effective pull for value |

| | |
|---|---|
| Perfection | 6.1 -Make effective use of existing program management and organizational maturity standards |
| | 6.2 -Pursue Lean for the long term |
| | 6.3 -Strive for excellence of program management and systems engineering |
| | 6.4 -Use lessons learned to make the next program better than the last |
| | 6.5 -Use change management effectively to continually and pro-actively align the program with unexpected changes in the program's conduct and the environment |
| | 6.6 -Proactively manage uncertainty and risk to maximize program benefit |
| | 6.7 -Strive for perfect communication, coordination and collaboration across people and processes |
| | 6.8 -Promote complementary continuous improvement methods to draw best energy and creativity from all stakeholders |

According to the Lean Aerospace Initiative (LAI) [4]Lean Thinking applied to product development context is aimed to: (1) creating the right products: creating product architectures, families, and designs that increase value for all enterprise stakeholders; (2) creating an effective lifecycle and enterprise integration: using lean engineering to create value throughout the product lifecycle and the enterprise; and (3) developing efficient engineering processes: applying lean thinking to eliminate wastes and improve cycle time and quality in engineering.

As all management approaches, Lean Product Development can be implemented through the adoption of tools, methods and best practices[5]. In particular, 43 Lean Enablers (LEs) have been identified as actionable best practices to be implemented in systems engineering programs in order to achieve the lean benefits and ultimately program excellence[2]. Table 1 summarizes the proposed enablers, which will serve as reference for the whole work proposed in this paper.

The Lean Enablers were developed by the Lean in Program Management Community of Practice, which was formed by the collaboration between MIT-PMI-INCOSE. The community was made up of selected subject matter experts from industry, government, and academia. The LEs are based on known best practices from the literature, program experience of the subject matter experts, and input from an extensive community of professionals. The validation was done through community and practitioner feedback, multiple workshops at INCOSE and PMI conferences, LAI - hosted web - based meetings, and surveys of the extended professional community. The survey results clearly show that programs that use the Lean Enablers show a significantly stronger performance in all dimensions—from cost, to schedule and quality, as well as stakeholder satisfaction.

## 3. The Lean Metrics

Improvement programs aimed to implement the Lean Enablers should collect and evaluate performance measures in order to identify if the benefits expected are achieved and if the best practices are indeed effectively implemented. Therefore understanding what are appropriate performance measures for Lean become extremely relevant.[6] Performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action [7], and hereafter in this paper it will be only referred as metrics.

Taisch et al [8] utters that performance metrics enables managers and employees to monitor and control resources and actions to achieve predefined targets. At the operational level, metrics are monitored and compared with the desired target. The comparison between actual performance and target performance identify gaps that can indicate the need for an improvement initiative. Furthermore metrics facilitate coordination among the multiple processes by communicating performance to the team and managers across processes. Coordination across processes results in timely and accurate actions, minimizing waste and improving overall performance.

As stated in previous section, the lean enablers can be applied to drastically improve systems engineering programs' performance, leading organizations through a literal lean revolution. Unfortunately literature lacks of a set of metrics able to capture the performance of a systems engineering program under the lean perspective. This absence represents a challenge for organizations to understand whether their lean journeys have being successful or not.

With the aim to fill this gap, this work is proposing a set of lean metrics to be tracked to ensure the implementation of the lean enablers is leading the program to the desired outcomes. An extensive literature review was carried out to identify the metrics used by engineering programs. A total of 52 literature – academic and practitioner – references were selected from which 153 different metrics were identified. To narrow down the collection of metrics extracted from the literature several focus group sections were done with subject matter experts from aerospace and government organizations and participants of the MIT-PMI-INCOSE Lean in Program Management Community of Practice.

One of the main results of the focus group discussions was the definition of four criteria to select the metrics that had potential to be used as indicators of the results of a lean journey. The first criterion that was established is the unit of analysis, with the following priorities: program or project level (high priority), department or process level (medium priority), and enterprise level (low priority). The second one is metric type regarding the provided insight: leading or lagging. The higher priority is associated with the greater tendency to provide leading insight. The third criterion is the lean principle fitness. This criterion is exclusionary, that is, the metrics must be aligned to one of the six lean principles (value, value stream, flow, pull, perfection, and respect for people). Finally, the number of times that each metric was mentioned in the literature was taken into account; the higher the number of citations, the higher its priority.

The 50 selected metrics were afterwards mapped with the Lean Enablers as presented in the following.

## 4. The mapping between the Lean Enablers and Metrics

As previous mentioned the Lean Enablers are best practices designed to assist the achievement of excellence in Engineering Programs. In order to achieve this excellence, program managers should carry on two analyses. First it is essential ensuring that the lean enablers are properly implemented, and second it is important to evaluate if the benefits of the implementation of the lean enablers were achieved. Both analyses can be assisted by metrics, yet it is important to differentiate the aim of these metrics.

The metrics focused on measuring the implementation level of the Lean Enablers are hereafter called implementation success metrics. These are the metrics that show the degree or quality of implementation of the Lean Enabler. The metrics aimed to measure the Lean Enablers benefits are hereafter called Program success metrics. These are the metrics that show improvement of program performance due to the effective implementation of the Lean Enabler.

Table 2 shows the mapping of the Lean Enablers with both of the types of metrics, the Implementation success metrics and the Program success metrics.

Program managers can also benefit from this mapping when deciding which Lean Enabler should be implemented. Oftentimes some programs have previously established, as strategic goal, the achievement of a target performance. Therefore, a further analysis of Table 2 can indicate which Lean Enablers is related to metric that is aimed to improve.

Table 2. Lean metrics versus Lean Enablers.

| Lean Enabler | Implementation Metrics | Program Metrics |
|---|---|---|
| 1.1 Build a program culture based on respect for people | - Average R&PD personnel turnover<br>- Employee satisfaction<br>- Labour relations climate between R&PD personnel | - New product quality level |
| 1.2 Motivate by making the higher purpose of the program and program elements transparent | - Quality of communication plan<br>- Employee satisfaction | - Level of employee awareness of R&PD program/projects' goals<br>- New product quality level<br>- Rate of successful product development projects |
| 1.3 Support an autonomous working style | - Labour relations climate between R&PD personnel<br>- Employee satisfaction | - Number and nature of bottlenecks<br>- Average project delay |
| 1.4 Expect and support people as they strive for professional excellence and promote their careers | - Average R&PD personnel turnover<br>- Labour relations climate between R&PD personnel<br>- Employee satisfaction<br>- Training in R&PD | - --- |
| 1.5 Promote the ability to rapidly learn and continuously improve | - Average R&PD personnel turnover<br>- Labour relations climate between R&PD personnel<br>- Employee satisfaction<br>- Training in R&PD | - New product quality level |
| 1.6 Encourage personal networks and interactions | - Quality of meetings<br>- Labour relations climate between R&PD personnel<br>- Employee satisfaction | - New product quality level<br>- Accuracy of interpretation of customer requirements |
| 2.1 Establish the value and benefit of the program to the stakeholders | - Rate of successful product development projects<br>- Customer satisfaction<br>- Progress against plan in assuring that the customer requirements are valid and properly understood | - Number and extent of requirement changes<br>- Accuracy of interpretation of customer requirements |
| 2.2 Focus all program activities on the benefits that the program intends to deliver | - Average project delay | - Program/Project met revenue goals<br>- Return-on-investment<br>- Rate of successful product development projects<br>- Time to market |
| 2.3 Frequently engage the stakeholders tthroughout the program lifecycle | - Alignment of R&PD strategy with company strategy<br>- Customer satisfaction | - Progress against plan in assuring that the customer requirements are valid and properly understood<br>- Accuracy of interpretation of customer requirements |
| 2.4 Develop high-quality program requirements among customer stakeholders | - Customer satisfaction | - Risk burndown |

| Lean Enabler | Implementation Metrics | Program Metrics |
|---|---|---|
| before bidding and execution process begins | | - Time to market<br>- Customer satisfaction |
| 2.5 Clarify, derive and prioritize requirements early, often and proactively | - Certified process | - Total cost of project<br>- Time to market |
| 2.6 Actively minimize the bureaucratic, regulatory and compliance burden on the program and sub-projects | - Certified process | - Total cost of project<br>- Time to market |
| 3.1 Map the management and engineering value streams and eliminate non-value added elements | - Total cost of project<br>- Certified process | - Usefulness of project outputs<br>- Average project delay<br>- Number and nature of bottlenecks |
| 3.2 Actively architect and manage the Program Enterprise to optimize its performance as a system | - Rate of maturity of the system definition against the plan | - Rate of successful product development projects<br>- Customer satisfaction |
| 3.3 Pursue multiple solution sets in parallel | - Number of solutions developed in parallel | - Time spent on changes to original product specification<br>- Product failure rates<br>- Customer satisfaction (with features, appearance, etc.) |
| 3.4 Ensure up-front that capabilities exist to deliver program requirements | - % On-time delivery of development project<br>- Utilisation of resources<br>- Utilization of personnel skills<br>- Facility and equipment availability trends | - Total cost of project<br>- Average project delay |
| 3.5 Front-load and integrate the program | - Utilization of resources | - Average project delay<br>- Actual versus target time for project completion<br>- % On-time delivery of development project |
| 3.6 Use probabilistic estimates in program planning | - | - Average project delay<br>- Actual versus target time for project completion |
| 3.7 Work with suppliers to proactively avoid conflict and anticipate and mitigate program risk | - Number of engineering changes<br>- Exploitation of relationships with partners | - Number of engineering changes<br>- Risk burndown |
| 3.8 Plan leading indicators and metrics to manage the program | - Delivery of product to cost (as quoted)<br>- Time to market<br>- Average project delay<br>- % On-time delivery of development project | - --- |
| 3.9 Develop an Integrated Program Schedule at the level of detail for which you have dependable information | - % On-time delivery of development project<br>- Average project delay | - Delivery of product to cost (as quoted)<br>- Total cost of project<br>- Actual versus target time for project completion<br>- % On-time delivery of development project |
| 3.10 Manage Technology Readiness Levels and protect program from Low-TRL delays and cost overruns | - Technology maturity | - Time to market<br>- Average project delay |
| 3.11 Develop a Communications Plan | - Quality of communication plan | - Effectiveness risk management process |

| Lean Enabler | Implementation Metrics | Program Metrics |
|---|---|---|
| | | - Customer satisfaction |
| 4.1 Use systems engineering to coordinate and integrate all engineering activities in the program | - New product quality level<br>- % Of projects/programs respecting costs and budget<br>- Number and nature of bottlenecks | - % Technical specifications met or exceeded, averaged across completions<br>- Customer satisfaction<br>- Technical performance measurement summary |
| 4.2 Ensure clear responsibility, accountability and authority (RAA) throughout the program from initial requirements definition to final delivery | - Employee satisfaction | - Usefulness of project outputs<br>- Total cost of project<br>- Number and nature of bottlenecks |
| 4.3 For every program, use a program manager role to lead and integrate program from start to finish | - Employee satisfaction<br>- Customer satisfaction | - Total cost of project<br>- Average project delay<br>- Number and nature of bottlenecks |
| 4.4 The top level program management overseeing the program must be highly effective | - Employee satisfaction<br>- Customer satisfaction | - Average project delay<br>- Number and nature of bottlenecks |
| 4.5 Pursue collaborative and inclusive decision making that resolves the root causes of issues | - Employee satisfaction<br>- Faster decision making process | - New product quality level<br>- Number and nature of bottlenecks |
| 4.6 Integrate all Program Elements and Functions through Program Governance | - --- | - Total cost of project<br>- Average project delay<br>- Customer satisfaction<br>- Number and nature of bottlenecks |
| 4.7 Use efficient and effective communication and coordination with program team | - Employee satisfaction<br>- Quality of communication plan | - Total cost of project<br>- Average project delay<br>- Customer satisfaction<br>- Number and nature of bottlenecks |
| 4.8 Standardize key program and project elements throughout the program to increase efficiency and facilitate collaboration | - Time to market<br>- Average project delay | - Employee satisfaction |
| 4.9 Use Lean Thinking to promote smooth program flow | - Number and nature of bottlenecks | - Quality for project completion (Qpc)<br>- Rate of successful product development projects<br>- % On-time delivery of development project |
| 4.10 Make program progress visible to all | - Actual versus target time for project completion<br>- % On-time delivery of development project | - % Of projects/programs respecting costs and budget<br>- Rate of successful product development projects<br>- Average project delay |
| 5.1 Pull tasks and outputs based on need, and reject others as waste | - Usefulness of project outputs | - Number of engineering changes<br>- Total cost of project<br>- Average project delay |
| 5.2 Establish effective contracting vehicles in the program that support the program in achieving the planned benefits and create effective pull for value | - Average project delay<br>- Actual versus target time for project completion<br>- % On-time delivery of development project | - Time to market |
| 6.1 Make effective use of existing program | - Employee satisfaction % | - % Of projects/programs respecting costs and |

| Lean Enabler | Implementation Metrics | Program Metrics |
|---|---|---|
| management and organizational maturity standards | - Of respected milestones<br>- Customer satisfaction | budget<br>- New product profitability<br>- Program/Project met revenue goals<br>- Rate of successful product development projects<br>- Average project delay |
| 6.2 Pursue Lean for the long term | - Rate of successful product development projects<br>- % On-time delivery of development project<br>- Number and nature of bottlenecks | - New product quality level<br>- Delivery of product to cost (as quoted)<br>- Rate of successful product development projects<br>- % On-time delivery of development project<br>- Customer satisfaction |
| 6.3 Strive for excellence of program management and systems engineering | - % On-time delivery of development project<br>- Customer satisfaction<br>- Number and nature of bottlenecks | - Quality for project completion (Qpc)<br>- Rate of successful product development projects |
| 6.4 Use lessons learned to make the next program better than the last | - Employee satisfaction | - New product quality level<br>- Rate of successful product development projects<br>- % On-time delivery of development project<br>- Customer satisfaction<br>- Number and nature of bottlenecks |
| 6.5 Use change management effectively to continually and pro-actively align the program with unexpected changes in the program's conduct and the environment | - Risk burndown | - Time spent on changes to original product specification<br>- Number of engineering changes<br>- Number and extent of requirement changes<br>- Number and nature of bottlenecks |
| 6.6 Proactively manage uncertainty and risk to maximize program benefit | - Rate of successful product development projects<br>- Effectiveness risk management process | - Risk burndown<br>- Customer satisfaction<br>- Number and nature of bottlenecks |
| 6.7 Strive for perfect communication, coordination and collaboration across people and processes | - Labour relations climate between R&PD personnel<br>- Employee satisfaction<br>- Quality of communication plan | - New product quality level<br>- Customer satisfaction<br>- Number and nature of bottlenecks<br>- Number and extent of requirement changes |
| 6.8 Promote complementary continuous improvement methods to draw best energy and creativity from all stakeholders | - Number and nature of bottlenecks<br>- Rate of successful product development projects | - New product quality level<br>- % On-time delivery of development project<br>- Customer satisfaction |

## 5. Discussions and future research

When properly undertaken, the lean journey leads companies toward excellence. However the application of lean philosophy is extremely challenging, especially in systems engineering programs. The 43 lean enablers, deriving from real best practices experiences, serve as a concrete support for that. But how to be sure the implementation of the enablers is appropriate and hence leads companies to improved performance? This paper - thanks to a deep literature investigation refined through a series of focus groups with the Lean in Program Management Community of Practice (MIT-PMI-INCOSE) - proposes a list of metrics to be considered in order to measure the performance affected by the introduction of the 43 enablers. Only when measuring the current situation of the program in fact, it is possible to direct improvement efforts. The main contribution of this paper is therefore the suggestion of what to measure.

Further step of this research are in term of how to use what it has been measured. Very often in fact, organizations track some performance of their systems engineering programs with no practical purpose and/or they don't track any metrics able to give information on the effectiveness of the improvement strategy in place. The idea for further studies is to understand whether tracking those metrics longitudinally will serve as an indicator of the goodness of the implementation of the Lean Enablers. The main purpose is to give a concrete support to organizations not only in term of what to measure, but also on how to use it in order to be sure the lean journey is going in the proper direction.

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