PM World Journal
Vol. III, Issue III – March 2014
www.pmworldjournal.net

Implementation of Lean Engineering through Simulation Based Training
By Shtub, Iluz, Gersing
Oehman, Dubinsky

Featured Paper

Implementation of Lean Engineering Practices in Projects and Programs through Simulation Based Training

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Abstract

Teams in engineering projects face complex decisions on a daily basis. In order to meet or exceed stakeholders' needs and expectations project teams must plan and re-plan their project to keep it on track. Their decisions are made in an uncertain, dynamic and constrained environment spanning a large variety of areas such as outsourcing decisions, design decisions, risk management decisions, resource related decisions, budgets and schedule related decisions etc.. Their purpose is to lower cost, reduce rework minimize paperwork, and eliminate duplicate efforts. Teamwork is essential in this challenging environment and a shared understanding of the project goals and constraints is the foundation of teamwork.

This paper describes our experience in using Simulation Based Training (SBT) and in particular, its contribution to the implementation of Lean Management Practices ("Lean Enablers") among project team members and stakeholders in two different industries in order to lead to better project outcomes in terms of time, performance, cost, and stakeholders' approval.

1.   Introduction

a.   Lean Enablers

The Lean Enablers are a set of Lean best practices, which have been developed specifically for the improvement of large-scale engineering programs. There are 43 Lean Enablers in total, which are sorted according to the six Lean Principals (value, value stream, flow, pull, perfection, respect for people) as shown in Figure [1].
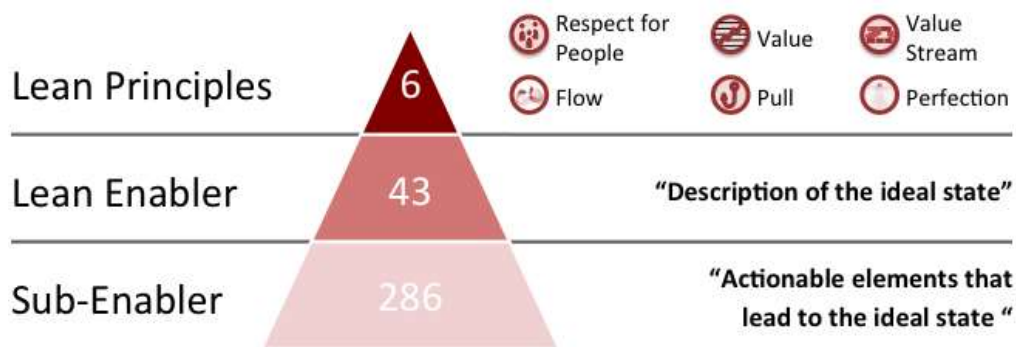
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Figure 1: Lean Principals, Lean Enablers and Sub-Enablers

The following section will introduce each of the Lean Principles in a little more detail [1]–[3]:

1. **Respect for People** – Seeing employees as the most important and valuable resource is critical for creating a high-performance working environment. The Lean methodology suggests encouraging the people to honestly address problems and obstacles, find out their root causes, collaboratively develop corrective actions and find a common consensus to prevent such problems in the future.

2. **Value** – It is important to capture the value defined by internal and external customer stakeholders, the external customer being the one who defines the final value of the deliverable.

3. **Value Stream** – The entire value stream needs to be mapped in order to identify and eliminate all non-value-adding activities, minimize all necessary but non-value-adding activities and make sure that all value-adding activities can flow without rework, backflow, or stopping.

4. **Flow** – In engineering programs, information should be able to flow from value-adding steps in streamlined process without stopping, unplanned rework, or backflow. Among the necessary conditions to achieve the state of perfect flow is a detailed capture of customer value, a good enterprise-level preparation, as well as an effective program planning.

5. **Pull** – The costumer stakeholders must pull the value. This implies two important meanings: Firstly, any task in a program must meet a specific need by a customer stakeholder. Any other task must be carefully examined and eliminated in case it is unnecessary. Secondly, every task must be delivered exactly when the customer stakeholder requires it. Early completion can lead to wasteful complications through e.g. the loss of human memory or a change in requirements.

6. **Perfection** – It is important to pursue perfection of products and processes. The degree of perfection for the product, or the output of a process, need to meet the value proposition, which defines when an output is good enough.

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The first Lean Enabler of the first Principle, for example, states: "Build a program based on respect for people". The first Subenabler of this Enabler then states, "Understand that programs fail or succeed primarily based on people, not processes. Treat people as the most valued assets, not as commodities." The Subenablers give more details on what needs to be undertaken in order to fully implement the Lean Enabler. The Guide to Lean Enablers for Managing Engineering Programs (Oehmen et al. 2013) furthermore gives a number of examples for each Lean Enabler, shows which program performance domain the Lean Enabler is relates to, indicates which challenge the Lean Enabler addresses and also links each Lean Enabler to the appropriate process number of the systems engineering process.

In order to determine the impact of the Lean Enablers, "best in class" programs were analyzed for the use of Lean Enablers. The result of this analysis was, that the three most highly successful programs, on which the amount of detailed information was enough for the analysis, used 60% to 75% of all the Lean Enablers. After the rough analysis, a second, more detailed analysis was conducted, based on a survey, in which the performance of successful and unsuccessful programs, as well as the degree to which they used the Lean Enablers was asked. The strong results of the survey showed, that successful programs have more Lean Enablers implemented than unsuccessful ones. **Error! Reference source not found.**2 ummarizes the results of the survey and clearly emphasizes the difference in performance between successful and unsuccessful programs [4].
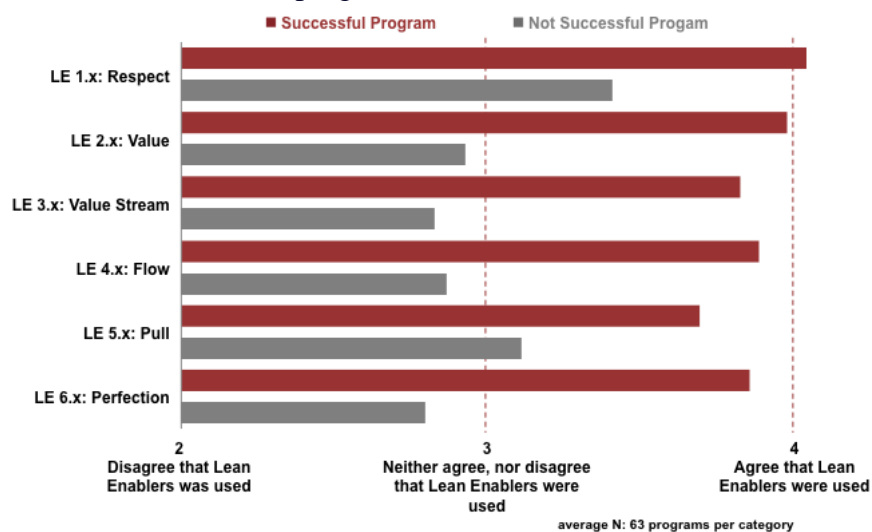

Figure 2: Successful program show significantly higher performance than unsuccessful programs

b.   Simulation Based Training and the Project Team Builder Simulator (PTB)

The essence of Simulation Based Training is that we must do things ourselves in order to really understand them. In his article, James I. Grieshop [Grieshop 1987] stated that: "Games and simulations (ranging from role playing to case studies, from guided fantasy to problem solving) have become widely recognized methods for instruction and learning. Since the early work in the United States in the late 1950s and in Europe in the late 1960s, gaming/simulation has become increasingly important to training and decision-making processes in academic settings as well as in business, the military, and the social sciences."

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Simulation Based Training (SBT) is a powerful tool that can be employed for training the Lean project principles. We found SBT to be instrumental in the creation of shared understanding among team members and, in addition, to improve tradeoff analysis and decision-making. Our pilot study in RAFAEL and IBM suggests that SBT can be used effectively to build project teams. Teams can be trained using SBT with a focus on the real project assigned to the team. By simulating a scenario based on the real project, the team can learn how to integrate the different aspects of project management, and – more importantly – can learn to work and solve problems together.

The Project Team Builder (PTB) http://www.sandboxmodel.com/ is a simulation based training simulator for Project Management. The simulator includes a pool of scenarios arranged according to their level of difficulty. Below is a screenshot of this scenario pool – Figure 3:
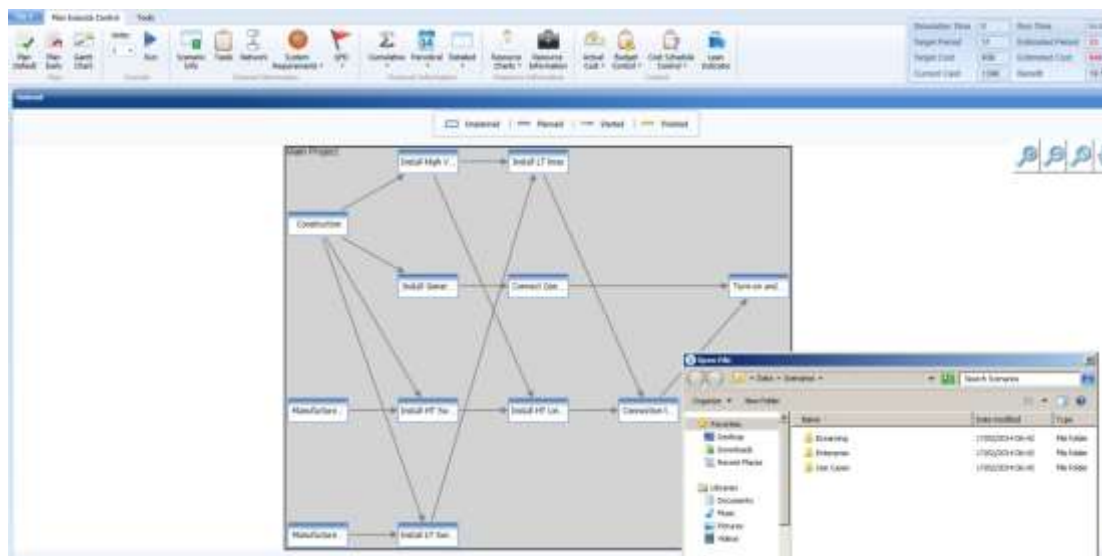

Figure 3: Scenarios pool

The PTB simulator includes a module for requirements management that supports the process of selecting alternative designs that determine system performance. Trainees have the option of interactively experiencing the decision making process. They have the opportunity to cope with the project execution resulting from these decisions.

A lean indicator report built into the Project Team Builder present the sources of waste and the value generated by the project. The value is calculated as a weighted sum of customer requirements based on the Quality Function Deployment (QFD) logic.

The lean indicator report identify infeasibilities in project scope (due date violation, budget violation and cash flow violation), as well as violation of product scope (requirement that are not satisfied and gold plating or overdesign of products with respect to some requirements). The Lean Indicator report is presented in Figure 4.

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Figure 4: Lean Indicator report

In Figure 4 the value to the customer is 76% while there are two sources of waste: Idle cost of resources and a penalty for late delivery. The due date or time constraint is violated i.e. the project is late and the requirements are all satisfied although the last one (Reliability) is gold plated or over designed.

2.   Using PTB in Workshops in R&D Organizations

This section describes our experience using a simulator for training Program in industry. We conducted two types of workshops in RAFAEL and IBM. Attendees were managers in different Research and Development (R&D) settings.

Rafael Advanced Defense Systems Ltd. develops and produces state-of-the-art defense systems for the Israel Defense Forces (IDF) and Israel's defense system. The company provides innovative solutions on the technological cutting edge from underwater, naval, land and air through space systems. RAFAEL focuses on such areas as Electronic Warfare (EW), Command, Control, Communications, Computers and Intelligence (C4I), training and simulators, armor and precision-guided weapon systems. The company has also formed partnerships with civilian counterparts to develop commercial applications based on its proprietary technologies. Rafael is the second largest government-owned defense company in Israel.

The IBM Haifa Research Laboratory (HRL) (http://www.haifa.il.ibm.com/) is IBM's largest research laboratory outside of the United States, employing almost 500 researchers, the majority of whom hold PhD and master's degrees in computer sciences, electrical engineering, mathematics, and related fields. Since its founding in 1972, HRL has conducted research vital to IBM's success. R&D projects are being executed today in areas such as healthcare and life science technologies, telco, machine learning, mobile, cloud computing, multimedia, information retrieval, programming environments, and optimization technologies.

Methodologies for simulation-based training have been developed and 2 types of workshops have taken place:

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- Full one day, or two days workshop including lectures and hands-on experience where participants build a scenario based on a real project with the goal of maximizing performance under schedule ,cost, quality and resources constraints based on Lean PM methodology.

- Before the project starts (the Fuzzy Front End of the Project) project teams are trained by PTB how to implement the Lean development methodology on their real-life future project. Team members learn how to evaluate the alternative plans for the project. An efficient frontier of project plans is generated by PTB and the team members learn how to trade off cost, benefit and duration and to find the best plan for their project.

The workshops were successful, both in terms of professional enrichment and in providing information to the participants, including familiarity with the Lean principles and in terms of building a team, creating communication and creating a common language amongst team members, shared understanding of targets and goals of the project.

Some insights gained from the workshops are:

1. The workshop is suitable for various levels of experience, both experienced and inexperienced PM's and SE's. The workshop can be conducted in variable class sizes (8-40 participants).
2. Hands-on experience and training can be achieved rapidly even within a day. Expanding the time frame to two days allows better training and increased levels of experience, which can be attained by tapping into higher levels of the tool's capabilities (for example in a two days workshop participants created their own scenarios and simulated the scenarios on the PTB).
3. Participants learned how to work with the tool and could subsequently continue to work individually to achieve the desired level of expertise.
4. The tool contributes to creating shared understanding and to amalgamating team members towards their joint work on the real project.
5. Providing feedback during the workshop regarding the team's achievements and analyzing the results of their decision-making indeed illustrates the Lean principles and contributes to the understanding as to where the team can be more productive, eliminate waste and improve.
6. The workshops using this tool demonstrated the technical and the managerial aspects (i.e., the integration of the system engineering world with the world of project management) within one integrative picture of the project and ties together three measures of project success (duration, cost and performance) within the world of Lean principles.

3.   Process of mapping Lean Enablers to PTB capabilities

According to (Gersing 2013) the process of evaluating the overall value of simulations for the implementation of Lean Enablers is done through a five-step utility value analysis, which is based on [5], [6, p. 175]:

1. Determination of target criteria

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2. Weighting of each target criterion
3. Calculation of partial utility values
4. Calculation of (total) utility values
5. Assessment of profitability

Since the purpose of the simulation is to address and implement the Lean Enablers, the target criteria in this utility value analysis is implementing the Lean Enabler itself. The weighting is kept very simple by assuming, that if a Lean Enabler is supposed to be implemented the degree of importance of the target criterion is weighted as "one" or 100%, and if not then "zero" 0%. In order to calculate the partial and the total utility value of a simulation, it is necessary to determine to which degree the simulation addresses each Lean Enabler. For this determination, a solid five-step process was designed, which resulted in an accurate and detailed mapping. Figure-5 shows this process.

Figure 5: Five-step process for the determination of the degree of fulfillment of a simulation

Several simulations were mapped this way, including the PTB-Simulator. For this paper only the PTB is of relevance. The first step was the active participation in a workshop where the PTB was directly applied. This was considered necessary in order to deeply understand how the demonstration tool worked and what it covered. In the next step, the degree to which the PTB addressees or implements each specific Lean Enabler was estimated. The scale for the degree was chosen as follows:

- 9: Demonstration Tool **directly** addresses the Lean Enabler
- 3: Demonstration Tool **indirectly** addresses the Lean Enabler through how it is done
- 1: Demonstration Tool **barely** addresses the Lean Enabler
- 0: Demonstration Tool **doesn't** address the Lean Enabler

This preliminary estimation was then validated in a first round interview with an expert on the PTB. In the next step the suggestions from the expert were implemented in the mapping. Finally the mapping was validated win a second round interview. The mapping can be seen in the Appendix.

4.   Selection of Lean Enablers for the workshop

As a result to the process explained in the previous chapter, it was evaluated that the following Lean Enablers were addressed directly by the PTB-Simulator and thus can be implemented through its use. The first number in front of each Enabler indicates the Lean Principle and the second the number for the Enabler in the Principle.

- 2.5: Clarify, derive and prioritize requirements early, often and proactively
- 3.2: Actively architect and manage the Program Enterprise to optimize its performance as a system.

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- 3.4: Ensure up-front that capabilities exist to deliver program requirements
- 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
- 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
- 4.6: Integrate all Program Elements and Functions through Program Governance
- 4.10: Make program progress visible to all
- 6.3: Strive for excellence of program management and systems engineering

The main result of the mapping is, that these 11 Lean Enablers can be implemented very well using the PTB-Simulator.

5. Summary

Confucius said: "I hear and I forget. I see and I remember. I do and I understand."

We have to experience some things on our own in order to really understand them.

In this paper we discuss ideas, tools and techniques that can help project managers, project team members and Systems engineers cope with the implementation of the Lean Enablers. We focus our discussion on the Lean Enablers which can be measured and employ training using SBT and specifically the PTB simulator.

Implementing lean management originated in improving the competitiveness of the organization by streamlining and improving processes within the organization, and achieving rapid and substantial savings in operating costs.

The initial steps for implementing and achieving improvements lie in understanding the Lean principles, the Lean Enablers and implementing the tools and techniques of the Lean methodology.

The simulation-based learning workshop supports the study of Lean project management principles in a complex uncertain environment.

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Appendix: Mapping of the Lean Enablers to the PTB

		Degree	Comment
Lean Enablers to Treat People as Your Most Important Asset			
1,1	Build a program culture based on respect for people	3	In beginning of the case study, everybody needs to understand the case and the meaning of the wording
1,2	Motivate by making the higher purpose of the program and program elements transparent	3	In the planning phase, the overall goal gets very clear, so everybody knows what they working towards
1,3	Support an autonomous working style	3	Once the tool is explained, the trainees get to do the simulatoin completely autonomously
1,4	Expect and support people as they strive for professional excellence and promote their careers	1	We expect the employees to strive for full compliance with the requirements of the costumer
1,5	Promote the ability to rapidly learn and continuously improve	3	The faster the trainees understand the interdependances, the better their simulation result will be
1,6	Encourage personal networks and interactions	3	Interactions between teammembers are necessary to reach a successful result
Lean Enablers to Maximize Program Value			
2,1	Establish the value and benefit of the program to the stakeholders	3	It is constantnly being monitored if stakeholders constraints and requirements will be met
2,2	Focus all program activities on the benefits that the program intends to deliver	3	It's a clear goal to focus all activities and ressources on the program benefit
2,3	Frequently engage the stakeholders throughout the program lifecycle	0	Not addressed in this simulation
2,4	Develop high-quality program requirements among customer stakeholders before bidding and execution process begins	3	The tool helps understanding the importance of clearly defining the requirements of the program. The tool can be used to develop high quality program requirements.
2,5	Clarify, derive and prioritize requirements early, often and proactively	9	It is an essential part of the planning phase of the PTB
2,6	Actively minimize the bureaucratic, regulatory and compliance burden on the program and sub-projects	0	Not addressed in this simulation
Lean Enablers to Optimize the Value Stream			
3,1	Map the management and engineering value streams and eliminate non-value added elements	3	There are no non-value added elements to start with
3,2	Actively Architect and manage the Program Enterprise to optimize its performance as a system	9	The PTB connects the project management with systems thinking
3,3	Pursue multiple solution sets in parallel	3	One team can run multiple simulations. From the technical side, only one solution is pursued
3,4	Ensure up-front that capabilities exist to deliver program requirements	9	The ressources can be adjusted at any time
3,5	Front-load and integrate the program	3	Frontloading is part of the planning process rather then of the simulation
3,6	Use probabilistic estimates in program planning	0	Not addressed in this simulation
3,7	Work with suppliers to proactively avoid conflict and anticipate and mitigate program risk	0	Not addressed in this simulation
3,8	Plan leading indicators and metrics to manage the program	9	Leading indicators need to be defined and constantly tracked (e.g. budget change rate)
3,9	Develop an Integrated Program Schedule at the level of detail for which you have dependable information	9	Program schedule is the main tool for the simulation
3,10	Manage Technology Readiness Levels and protect program from Low-TRL delays and cost overruns	0	Not addressed in this simulation
3,11	Develop a Communications Plan	1	The simulations helps establishing a flow of communication between the team members
Lean Enablers to Create Program Flow			
4,1	Use systems engineering to coordinate and integrate all engineering activities in the program	9	One of the main goals is to coordinate the engineering activities as a system
4,2	Ensure clear responsibility, accountability and authority (RAA) throughout the program from initial requirements definition to final delivery	9	Each trainee gets a specific roal in the group (initiating, planning, executing, monitoring, closing)
4,3	For every program, use a program manager role to lead and integrate program from start to finish	9	Program manager role should be announced in every group before starting the simulation
4,4	The top level program management (e.g., program management office) overseeing the program must be highly effective	3	Program manager in the team should always have an overview
4,5	Pursue collaborative and inclusive decision making that resolves the root causes of issues	3	It is possible to simulate scenarios in which several project managers manage their corresponding projects while sharing goals and constraints, e.g. resource constraints or cash flow/budget constraints.d
4,6	Integrate all Program Elements and Functions through Program Governance	9	The simulation does exactly that
4,7	Use efficient and effective communication and coordination with program team	3	Not explicitly announced but this is part of the group work
4,8	Standardize key program and project elements throughout the program to increase efficiency and facilitate collaboration	0	Not addressed in this simulation
4,9	Use Lean Thinking to promote smooth program flow	3	The tool identifies waste simulation after each step of the simulation
4,10	Make program progress visible to all	9	Program progress is made clearly visiable to all team members after every action through a Gantt-Chart
Lean Enablers to Create Pull in the Program			
5,1	Pull tasks and outputs based on need, and reject others as waste	0	Not addressed in this simulation
5,2	Establish effective contracting vehicles in the program that support the program in achieving the planned benefits and create effective pull for value	0	Not addressed in this simulation
Lean Enablers to Pursue Program Perfection			
6,1	Make effective use of existing program management and organizational maturity standards	0	Not addressed in this simulation
6,2	Pursue Lean for the long term	3	The high number of case studies allows to conduct simulation several times and thus pursue Lean on the long term
6,3	Strive for excellence of program management and systems engineering	9	Through the use of the PTB trainees shall become aware of the importance of high quality program management and systems engineering
6,4	Use lessons learned to make the next program better than the last	1	Lessons learned can be documented at the end of the simulation
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	0	Not addressed in this simulation
6,6	Proactively manage uncertainty and risk to maximize program benefit	3	There are certain risks integrated in the simulation that should be proactively managed
6,7	Strive for perfect communication, coordination and collaboration across people and processes	1	This is part of the group work, but isn't addressed explicitly
6,8	Promote complementary continuous improvement methods to draw best energy and creativity from all stakeholders	0	Not addressed in this simulation

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ACKNOWLEDGMENT

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