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A study on how to improve the throughput time of Lean Six Sigma projects in a construction company

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Abstract
Purpose – The purpose of this paper is to study the use of the Lean Six Sigma (LSS) methodology in a construction company.

Design/methodology/approach – In our study we analyze 62 LSS improvement projects carried out within a Dutch company. In our analysis we focus on both speed, in terms of throughput time (THT), and impact, in terms of project completion, of each project.

Findings – From the analysis we conclude that the current THT of a project is about a year and we identify important factors that cause large project's THTs These factors are then translated into recommendations for an efficient execution of LSS improvement projects.

Research limitations/implications – The analysis is based on a sample from one company of the Dutch construction industry. The scope should be broadened as more companies adopt quality and process improvement programs, such as LSS.

Originality/value – The narrowed scope, only one company and focused mostly on the speed of projects, helped to do an in-depth analysis. Therefore, we are able to present concrete and useful recommendations that relate to practical issues in the execution of improvement projects. These recommendations offer a checklist for construction companies in the project selection process, in situations of starting or improving an LSS program

Keywords Project management, Six Sigma, Lean thinking, Process improvement

Paper type Research paper

1. Introduction
Because clients are increasingly demanding high-quality and reliable products at low cost, and the construction industry faces an increased competitiveness caused by globalization and deregulation, established firms need to revise their strategy. These firms need to do so by building on their competitive strengths through a deliberate and managed process to improve the capacity and effectiveness of the industry, and to support sustained national economic and social objectives (Stewart and Spencer, 2006). Stewart and Spencer's study suggests that these goals development, in part, can be achieved by learning how to increase efficiency through process improvements.

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This is also true for the construction industry. Alwi *et al.* (2002) state that the construction industry is characterized by problems concerning variation, non-value-adding activities and waste. This is mainly caused by too much focus on the transformation process, in which materials are transformed into a tangible construction, without putting enough effort in creating flow of the activities involved.

Several studies have been conducted using concepts of process improvement in the construction industry, such as Six Sigma (Stewart and Spencer, 2006), lean principles (Kim and Park, 2006) and total quality management (Arditi and Gunaydin, 1997; Sommerville and Robertson, 2000). These process improvement techniques are developed and have proven their use in other industries, such as the production industry. One of the latest methods is a combination of lean and Six Sigma: Lean Six Sigma (LSS; De Mast *et al.*, 2006).

Lean aims to improve processes by reducing process instability (Muri), reducing process waste (Muda) and reducing process variability (Mura) (Womack and Jones, 1997). The process is improved from customer perspective, focusing on every process step required to design, produce, deliver and sometimes even maintain a product. These process steps form the *value stream*, which can "flow" through multiple departments of an organization and should be optimized as a whole. This optimization is realized by improving the capacity, reliability and responsiveness of each step of the value stream, so these steps can be synchronized to create an uninterrupted *flow* of process steps which is in line with customer demands and wishes (Jones, 2003; Womack, 2005). Because lean is focused on the entire value stream, to be able to realize lean production or construction, not only the actual process of producing or constructing should be lean but a complete lean business should be created. Lean, however, consists of principles such as reducing waste, but does not provide a framework that assists companies to really create a "lean business system" (Womack, 2007).

This framework can be provided by Six Sigma, a technique used to improve processes by a structured framework that is applied in a project. Six Sigma is focused primarily on process variation reduction. Because the quality of a product or process is strongly dependent on the gap between what is expected by a client and what is actually delivered, Six Sigma aims to realize a process that is as predictable as can be on all factors that drive customer satisfaction (Hahn *et al.*, 1999). Increasing predictability can be realized by decreasing the number of defects in a process. It is often argued that Six Sigma strives for a quality level equal to 3.4 defects per million products. In other industries, such as the service industry and the construction industry, attaining such a high-quality level is hardly realistic because it is much harder to treat defects equally (Antony, 2004). In the construction industry, a defect is defined as everything that is not in line with a client's specification (Harris *et al.*, 2006). This in contrast to what is seen in manufacturing, where a defect is defined as a product that does not meet the product specification. Therefore, Six Sigma is a philosophy aimed to continuously improve process quality rather than actually attaining the "Six Sigma" quality level.

In the construction industry, lean and Six Sigma already have been mainly used as individual methodologies. Lean construction, for example, is a widespread methodology managing the interaction of activities and the combined effect of independence and variation (Howell, 1999). An example of a tool that is often used in construction is lean planning, that makes use of the *Kanban* principle (i.e. the idea to control the work in process level).

As a methodology, LSS converged from the lean principles and the Six Sigma approach and combines the best of both worlds into a structured framework that reduces and eliminates process wastes (lean), defects and variation (Six Sigma) (Marsh *et al.*, 2011). In their research on the lean and/or Six Sigma user base, Marsh *et al.* (2011) argue that LSS is now the most widely used approach and has replaced lean and Six Sigma as individual methodologies.

However, companies in the construction industry seem reluctant in adopting process improvement techniques such as the LSS framework. According to Ferng and Price (2005), businesses in the construction industry have always ran behind other industries in the adoption of process improvement innovations, holding on to the firm belief that their industry is differing too much for these proven techniques to be useful or applicable to their processes. Due to this reluctance, only a few construction firms are known to use LSS, and there is very little literature available on such use.

In this paper, we study the use and performance (in terms of throughput time, THT) of LSS improvement projects in a Dutch construction company. The company strives to achieve an average project's THT of six months. In 2009, LSS was introduced in the company and the first LSS improvement projects were started. Only a few of the projects executed so far have managed to achieve the six-month THT, and the actual average THT is almost one year. In this paper, we assess the performance of the LSS projects in a construction company, and we identify important factors that cause large project's *THTs* for a given project. These factors are then translated into recommendations for an efficient execution of LSS improvement projects. These recommendations can help construction companies to improve the execution of their LSS projects, but can also be used as guidelines for the project selection process when starting up an LSS program.

2. LSS projects in a construction company

Our analysis is based on a sample of 62 LSS projects carried out within a Dutch construction company. The sample of projects represents a cross-section of the types of LSS projects carried out by the company: the projects vary along several key dimensions, such as type of department (property development and residential building, non-residential building, infrastructure, technical services and corporate services), type of process (tendering, project execution, etc.) and size (ranging from €54.000 to €640.000 worth of benefits). All LSS projects that at least finished the define stage at the start of this research project were taken into consideration when constructing our database. This total of 92 available projects reduced to 62 because 30 projects were stopped.

Within the domain of LSS, project leaders make use of several frameworks (Jones *et al.*, 2010). In this paper, however, we limit our study to process improvement project that use the Define-Measure-Analyze-Improve-Control (DMAIC) framework. An LSS project is managed according to the DMAIC phases. Each phase is completed only when specific milestones are reached (de Mast *et al.*, 2006). These milestones are represented by the project steps depicted in Table I.

According to Hambleton (2007), a DMAIC project typically runs for a relatively short time, three to nine months. The shorter the project THT, the better, as the project gains can be realized more quickly (Luci, 2009).

We follow the same DMAIC framework. This is suitable because an LSS project is a structured and repetitive process, and its THT is influenced by process variability and waste. Therefore, the framework provides a useful structure and tools to analyze and improve the execution of process improvement projects.

3. Assess and reduce the LSS improvement project's THT

In this section, we discuss our assessment by following the five DMAIC phases. Through this structure we actually run an LSS project over all the projects in the improvement program of the construction company under study. Therefore, the structure of this section is similar to a case study article of one of the LSS projects in the program we study (Lokkerbol *et al.*, 2011). We start to define the goal of our assessment. Then we measure and analyze the performance (in terms of the project's THT) of the LSS projects in our sample. The analysis is done with the help of the standard tools in LSS (De Mast *et al.*, 2012). From the analysis we conclude what the current performance is and identify causes for delay of improvement projects. Next, based on the causes we generate ideas to improve the performance. We finalize this section by indicating how these improvements should be implemented and how the performance can be monitored.

3.1 Define phase

A DMAIC project starts with a clear definition of the process. In our study, the process is the execution of an LSS improvement project. The objective of our study is to reduce the THT of LSS projects. The average THT that is pursued in the long run, defined by the organization, is fixed at six months. Financial benefits of this project are realized by LSS projects' benefits being realized earlier.

3.2 Measure

The next step is to link the project objective to specific and quantifiable process measures, the so-called critical-to-quality measures, or CTQs (De Koning and De Mast, 2007). In our study, the THT is decomposed into the CTQs processing time (PT) and waiting time (WT), as represented by the CTQ flowdown in Figure 1. On a higher level, the project objective links to the organization's strategic objectives, i.e. profit and quality, since the improvement projects.

To measure these CTQs, we state operational definitions, as shown in Table II. The operational definition of a CTQ consists of three elements. First, it is specified per which entity the CTQ is measured. This entity is called the (experimental) unit. Both *PT* and *WT* are measured per phase per project. Second, the measurement procedure for the CTQs is specified. Some of the required information can be extracted from the

Define	0. Define the project
Measure	1. Define the CTQs
	2. Validate the measurement procedures
Analyze	3. Diagnose the current process
	4. Identify potential influence factors
Improve	5. Establish the effect of influence factors
	6. Design improvement actions
Control	7. Improve process controls
	8. Close the project

Table I. The project steps of the structured DMAIC approach of LSS, based on De Mast *et al.* (2006)

organization's LSS team site; most of the information, however, is collected by making use of a questionnaire. Third, the goal for the CTQs is stated. In this case, it is to become as low as possible, for both CTQs.

Next, a validation of the measurement system is required to ensure the quality of the collected data, and thus the quality of the input for decisions to be made later on in the project. By validating the measurement system, we learned that project information on the team site was not up-to-date for most projects. Also, because project documentation was scarce and none of the LSS project leaders kept track of the number of hours invested in the project, only estimates for *THT* and *PT* per project phase could be determined through questionnaires. Due to the lack of data, estimates of the *WT* per project phase were derived from part of *THT* that is not *PT*, that is:

$$WT_x = THT_x - PT_x$$

where x refers to a project in our sample.

3.3 Analyze

From the *THT*s of the projects in the sample (Figure 2) we diagnose the current performance of the LSS projects within the company under study. In most improvement projects, the performance assessment is done by measuring the CTQs' performance. Due to the limited amount of reliable data for the CTQs, *PT* and *WT* per project phase, the process performance is expressed in terms of the total *THT* per project. The projects in our sample have an average total *THT* of 382 days. The longest project – 820 days, the shortest – 113 days and the 95 per cent confidence interval of the mean *THT*, that is {337 days; 430 days}. The Anderson-Darling normality test shows a P-value < 0.005. We

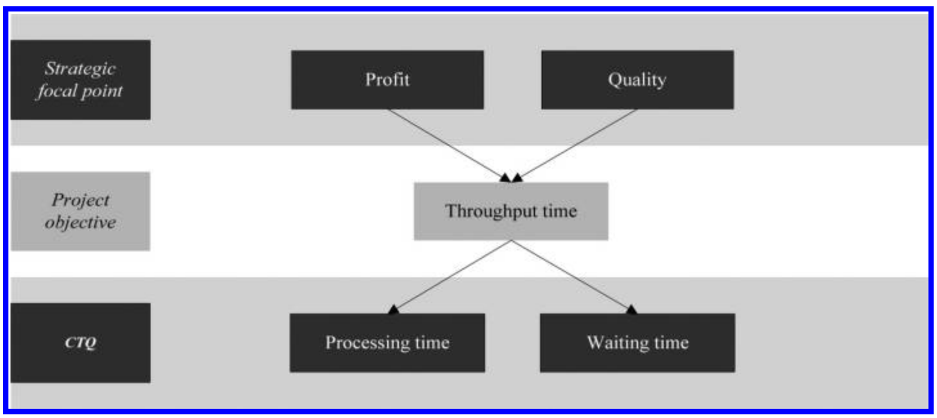

Figure 1.
CTQ flowdown for improving LSS project *THT*

Table II.
Operational definition for improving LSS project *THT*

CTQ	PT	WT
Unit	Per project, per step (days)	Per project, per step (days)
Measurement procedure	Via LSS team site, questionnaire	Via LSS team site, questionnaire
Goal (average)	Two days/week for six months	Five days/week for six months

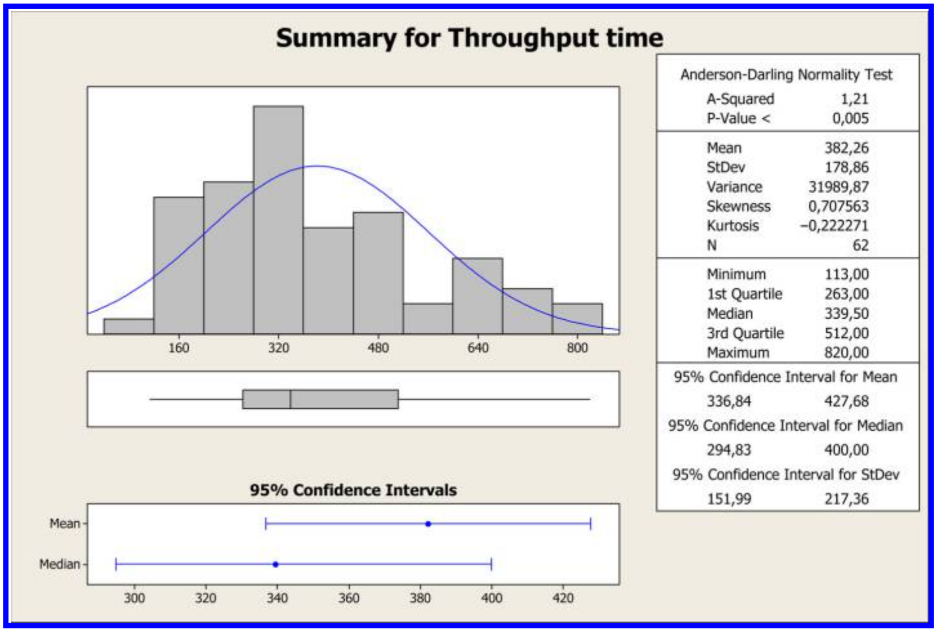

Figure 2. The graphical summary of the project's THT based on our sample of 62 LSS projects

conclude that the current *THT* of a project does not follow a normal distribution, and that an average project is not completed within the pursued *THT* of 180 days. At the same time, project leaders indicated that a significant reduction in THT can be realized through a reduction in unnecessary delays (driving the *WT* per project phase), which indicates there are potential improvements within reach of the program management to reduce this *THT* per project.

Unfortunately, little data on the *PT*s and *THT*s per project phase are available, which hinder in performing in-depth study to identify the main drivers of a large *THT* per project; for example, with the help of exploratory data analysis tools, as proposed by De Mast and Kemper (2009). Therefore, we make use of less data-driven tools to generate potentially valuable process information, that enables us to define targeted improvement in the process of LSS project execution. The focus in the rest of the paper will therefore be as follows:

- to identify causes for delay per project phase;
- to design improvements that reduce the delay per project phase; and
- to identify the required information and measurement system(s) to facilitate monitoring and continuous improvement of the process.

Causes of delay are called influence factors (de Mast *et al.*, 2006). These affect the behavior of the CTQs, in this case project *PT* and *WT*. Because these factors are the cause for substandard performance, they are the key to a better performance. We identify four types of influence factors:

(1) *Control variables* can be manipulated and controlled and are used to influence and adjust the process;

(2) *Nuisance variables* are sources of unwanted variation and have to be eliminated or compensated for;
(3) *Disturbances* are events that disrupt the regular process and thus affect the CTQ; and
(4) *Inefficiencies* are sources of waste, rework and redundancies and have to be eliminated.

There are different approaches to identify potential influence factors (De Mast and Bergman, 2006). It is important to initially identify as many potential influence factors as possible and then to select the more promising influence factors. This is in line with so-called branch-and-prune strategies that aim to balance between excessive divergence in generating possible influence factors and excessive convergence by rationalizing this set of factors through the selection of the most promising factors (De Mast and Lokkerbol, 2012). The toolbox of LSS offers generally known techniques that facilitate the process of generating possible influence factors (De Koning and De Mast, 2006). In our study, we use the following approaches:

- inventory of process know-how through a brainstorming with the LSS program management and interviews with the project leaders of our sample;
- technical literature and expert interviews; and
- failure modes and effects analysis (FMEA) to identify process disturbances.

3.4 Inventory of process know-how

During a brainstorming session, the LSS program management proposes and validates a questionnaire for all project leaders in our sample. The team consists of the master black belt and the nine black belts within the organization, who discuss the ways to collect required data and how to guarantee the quality of the data. Also, possible influence factors were discussed, namely:

- financial benefits realized by the project (indication of the scope of the project);
- existence of a project planning;
- completeness of training by the champion (problem owner); and
- number of hours initially scheduled for the project.

Next, seven in-depth interviews with LSS project leaders, both black and green belts, were carried out to identify problems encountered in their projects. The key issues that were identified by these project leaders and program managers were as follows:

- lack of available time, caused mainly by the lower priority that LSS projects have compared to daily, routine work;
- lack of knowledge concerning the LSS framework and project requirements, especially in the define and measure phase of the project; and
- lack of available process data, caused by difficulty in defining and finding the required data.

During these interviews, the project leaders also explained and clarified their answers in the questionnaire (concerning *THT* and *PT*) why certain project steps took significantly longer or required more man hours than other project steps. As an example, Table III shows the causes for delay mentioned by the project leaders for "Step 3. Diagnose the current process" in the analyze phase and "Step 5. Establish the effect of influence factors" in the improve phase.

3.5 Technical literature and expert interviews

Two expert interviews were conducted, one with the company's master black belt and one with a master black belt outside of the company. Based on these interviews, the following three factors were added to the list of influence factors:

(1) lack of planning;

(2) project scope often defined to broad and not based on a solid problem analysis; and

(3) the role of the champion in the control phase is not well defined.

The second factor, about the project scope, mentioned by the experts is in line with what is stated in literature. Dobriansky (2009) argues that the TTH is strongly dependent on the scope of the project.

3.6 Failure modes and effects analysis

During the execution of a project, the project leader or team experiences all kinds of disturbances that may delay the project. Because these disturbances are often hard to measure (in terms of frequency) or analyze (in terms of impact), we studied disturbances that could delay a project with the help of FMEA. FMEA is a tool for determining how a product, process or system may fail and the likely effects of particular modes of failure (Snee and Rodebaugh, 2008).

In our study, the FMEA method is used in a brainstorming session. During the session, two groups, both consisting of four project leaders, constructed an FMEA with help of standard FMEA-templates. Following the project steps as in Table I, the first group focused on LSS project Steps 0-3 and the second group on Steps 4-8. Initially, possible failure modes (referring to disturbances as influence factors) for every project step were identified, followed by a brainstorming session on possible causes For every disturbance the FMEA rates: the frequency (F) that each disturbance's cause occurrences (on a scale of 1: hardly ever to 10: almost continuously), the impact (I) of its effect (on a scale of 1 to 10), and the traceability (T) that indicates how hard it is to trace the cause of the disturbance (on a scale of 1 to 10).

The risk priority number (RPN) is determined by multiplying the ratings of the frequency, the impact and the traceability. This multiplication enables to capture the idea behind the FMEA: the higher the frequency and impact, and the harder it is to trace

Step 3. Diagnose the current process	Step 5. Establish the effect of influence factors
Skills and theoretical knowledge (tool usage)	Priority/time
Knowledge of framework	Organization of the project (i.e. availability of experts)
Organization of the project (i.e. assistance)	Align agendas of people involved
Availability of data and information	

Table III. Causes for delay in *PT* and *WT* in Steps 3 and 5 of an LSS project the cause, the higher a cause's risk is rated. The higher the RPN, the more a disturbance disrupts the regular process, and the higher it is ranked as an influence factor. A few results from the FMEA are shown in Table IV. This table shows a part of the results from the FMEA performed. The risk of the disturbance "wrong project definition" caused by "missing problem analysis" is rated highest. The frequency of occurrence ($F = 10$) and the impact on the project's THT ($I = 8$) are both high. Because it is argued that it is hard to trace this cause ($T = 10$), the RPN increases even more.

All the potential influence factors identified via the approaches described above are listed in a process matrix. The factors are sorted by type: control variable, nuisance variable, disturbance and inefficiency. Further screening of the identified influence factors is required to determine the (vital) few influence factors that really drive the CTQs' performance. This way, improvement actions for influence factors are focused on where they really make a difference. In this step, to screen the influence factors, we evaluate the expected effect (E) of an influence factor on the CTQs' performance. Also, we evaluate the level of changeability (C_1), or of compensability (C_2) in case of a nuisance variable, of an influence factor. Based on these evaluations, we select a number of so-called *vital* influence factors upon which we will focus during the improve phase of the LSS project.

The process matrix in Table V contains the vital influence factors. To focus improvement actions on influence factors that have a high impact on the CTQs' performance, we distinguished those factors that have a high effect (E) on the CTQs' performance and are easy to change or compensate. Consequently, influence factors are only marked as vital if $E \geq [\pm]$ and $C_{1,2} \geq [\pm]$, for control variables, nuisance variables and efficiencies. For disturbances, we marked disturbances as vital if the *RPN* rated at least 200. The matrix also denotes the relation between CTQs and variables (control or nuisance), as well as the process step in which the CTQ is affected by an influence factor.

3.7 Improve

In the improve phase of the project, a project leader designs improvement actions that link to a selection of the vital influence factors, the so-called vital few influence factors. In our research project, the improvement actions should link to the vital few influence factors that are expected to have a large effect on the *THT* and the success of the project. In case of control variables, nuisance variables or inefficiencies, we

Step	Disturbance	Cause	*F*	Effect	I	Tracing method	T	RPN
0	Wrong project definition	Solution instead of a problem	5	Rework	5	Review	4	100
		Top-down project selection	8	Decrease of motivation	10	Along the way	7	560
		Missing problem analysis	10	Not actual/right problem solved	8	–	10	800
0	Project scope is defined too broad	Ambition of the champion	8	Expanding the project	10	Review	4	320
		Ambition of the project leader	5	Expanding the project	8	Review	4	160

Table IV.
A few results from the FMEA

Process step	*Influence factor*	*PT*	*WT*	*E*	C_1
Control variable					
Entire process	Number of hours invested per week	x	x	[+]	[±]
Entire process	Presence of project planning (yes/no)		x	[±]	[+]
Entire process	Number of green/black belts in project team	x	x	[±]	[+]
Entire process	Number of yellow belts in project team	x	x	[±]	[+]
Entire process	Yellow belt completed training (yes/no)	x	x	[±]	[+]
Entire process	Champion completed training (yes/no)		x	[+]	[+]

Process step	*Influence factor*	*PT*	*WT*	*E*	C_2
Nuisance variable					
Entire process	Knowledge of project	x		[+]	[±]
Entire process	Align agendas of people involved	x	x	[+]	[±]
Entire process	Nature of process hinders project execution	x	x	[±]	[±]
Step 0	Change of champion		x	[±]	[+]
Step 0	Project leader lacks process understanding	x		[±]	[±]
Step 5	Availability of experts	x	x	[+]	[±]
Step 6	Availability of "key persons"	x	x	[+]	[±]
Step 7	Feedback on implementation plan		x	[±]	[±]

Process step	*Disturbance*	*Cause*	*F*	*I*	*T*	*RPN*
Disturbance						
Step 0	Wrong project definition	Problem analysis	10	8	10	800
Step 0	Wrong project definition	Project selected top-down	8	10	7	560
Step 1	Expanding scope	Assistance	3	8	10	240
Step 3	"Muddle along" too long	Continue "at all costs"	3	10	7	210
Step 7	Not assigning responsibilities	Person not present	10	5	4	200
Step 7	Not assigning responsibilities	Project leader powerless	10	5	4	200
Step 7	Incorrect implementation plan	False definition of actions	5	8	7	280
Step 7	Incorrect implementation plan	False division of tasks	8	8	7	448

Process step	*Inefficiency*	*E*	C_1
Inefficiency			
Step 0	Over-processing due to unsuitable project	[+]	[±]
Step 2	Rework due to validating wrong data	[±]	[+]
Step 3	Rework due to performing wrong analysis	[±]	[+]
Step 3	Waiting for required data	[+]	[±]
Step 4	Rework due to lack of validated data	[+]	[±]
Step 4	Waiting for required knowledge (brainstorming, etc.)	[+]	[±]
Step 4	Waiting for required data	[+]	[±]
Step 5	Rework due to wrong method for proving effect of influence factor	[+]	[+]
Step 5	Over-processing due to ambition to find the most vital factor	[+]	[±]
Step 6	Waiting for required support (champion, other project drivers)	[+]	[±]
Step 7	Waiting due to lack of proven usefulness of improvement actions	[+]	[±]

Table V. Process matrix: vital influence factors in LSS projects

selected the vital few influence factors based on their rating with respect to effect and changeability or compensability, C_1 or C_2. In case of disturbances we selected the vital few influence factors based on the level of the RPN components. In the end, we selected an influence factor if it was rated as [+] for both effect and changeability/compensability or if it was rated > 5 on all RPN components.

To establish the effect of an influence factor, in terms of reduction of the project's *THT* and the success of the project, we could rely on statistical analysis (in case of empirical support) or through the execution and monitoring of several pilot projects. Here, we choose to verify the improvement actions through the execution of several pilot projects. Consequently, we do not quantify the effect of an improvement action, but verify whether it is likely to work.

The vital few influence factors selected from Table V are as follows:

- champion completed training (yes/no);
- incorrect problem definition due to broad scope and poor problem structuring;
- incorrect problem definition due to top-down selection;
- rework due to incorrect verification method for improvement actions; and
- incorrect implementation plan due to incorrect task assignment.

Most of these identified factors are well-known in project management literature, for instance, described by Winch (2010), or are in line with factors that are important to the success of a complete LSS program (Jeyaraman and Teo, 2010). However, this does not hold for factor 2. An extensive problem analysis and structuring is an activity that is usually overlooked when defining the project's goal of improvement projects in construction. If the problem is not clear, the project's objective will remain vague and the process metrics that need to be improved to realize the objective are hard to find.

Based on these influence factors, we design four *improvement* actions. Here we list the improvement actions and per action the influence factor it links to:

- The project has priority and should be a part of daily work just as any other project. This requires the commitment of both project leader and her or his manager. Sufficient time should be made available for the project leader by the manager, and the project leader should utilize this time as efficiently as possible for the improvement project (Factors 1 and 5).
- A realistic project planning and milestones are created before the start of the project; this planning is tuned with other daily activities of the project leader. Also, the project team should arrange and plan monthly team meetings to keep all team members involved (Factors 1 and 5).
- The project leader and the champion should identify and scope the problem *before* the start of the project. This way a correct and actionable project definition, that is the identification and scoping, is obtained. The problem definition becomes an active part of the champion training (Factors 2 and 3).
- Clear deliverables for the verification of improvement actions. The LSS program team states that each improvement or set of improvements should be verified through statistical analysis, a pilot study or measuring the improved process performance (Factor 4).
- Commitment of the champion is of crucial importance in the control phase of LSS projects. The implementation of improvement actions can only be realized if the right people are made responsible for the right tasks. Because the champion is the "owner" of the process and is accountable for the process performance, the champion has the legitimate power to assign these people to execute improvement actions (Factor 5).

3.8 Control

In the control phase of our study, we aim to structure the quality control system of the process, so that it is able to embed the improvement actions of the previous phase and retain the improved results, that is to retain the reduced THT of the LSS to guarantee a completion time of about six months.

The LSS tools in the control phase typically focus on clearly defining responsibilities, visualizing the process performance and standardizing responses to irregularities such as a delay in a project or diminishing project impact (De Mast *et al.*, 2003).

4. Conclusions

Our study of 62 LSS improvement projects in the construction industry generates a broad view on the performance, in terms of THT and success, of these projects. To the best of our knowledge, in the construction industry, there is no large-scale study of an LSS program available. This fact makes it interesting to assess the performance of projects in this program.

The research shows that two years after the method was introduced, the THTs of these projects are still larger than the target duration required by the organization. Also, our research provides us with an overview of the most important problems that project leaders encountered in executing the projects using the DMAIC framework of LSS.

The main drivers for these overruns are in line with existing project management literature. First, the LSS improvement projects are given insufficient priority by the project team, there is often uncoordinated track of project progress due to a lack of planning and communication and not all project team members are sufficiently committed to the project. Due to the project-based approach of the LSS DMAIC framework, these problems that drive the project's THTs can be dealt with using project management tools and techniques, such as a Gantt chart and an analysis of the political force field.

Another problem that was identified as a major cause for project delay concerned the problem structuring that is required to both define the project's scope and to unravel the problem into sub-issues. This project step is often overlooked or executed to a dramatically limited extent. These findings are in line with what is pinpointed in literature (Lynch *et al.*, 2003; Partington, 1996), which claims that the project definition is a crucial part of the success of a project. Future research could aim to provide CTQ flowdown templates, similar to De Koning *et al.* (2010), that predefine common problem structures that relate to processes in the construction industry, or to provide typical measurement plans, similar to Kemper and De Mast (2013), that can be used in improvement projects in the construction industry.

Our research has some limitations. The sample is representative to a certain extent because we collected data from one company in the Dutch construction industry, and, for example, only few projects were focused on improving processes in the tender phase of a construction project. But, as Lokkerbol *et al.* (2012) also state, our case base is not intended as a basis for strong claims about which types of improvement projects should be run by a construction company. We propose best practices represented in our case base as a source of valuable knowledge in itself.

Also, improvement actions for the LSS projects are limited to focus areas to be used at the level of LSS project management. The design and realization of improvement actions that are aimed at specific DMAIC process characteristics are required to further optimize the execution of improvement projects. To do so, more detailed process data need to be collected, for example through registering the hours spent per project step.

5. Discussion

Like with any other process improvement method, organizing and implementing LSS is a costly investment for any type of business. It requires a solid organization of tasks and responsibilities in every layer of the organization, and process monitoring systems must be developed to assemble the data required to execute an LSS project. It takes time and serious effort to establish a well-organized LSS program, but the cost reductions realized by the LSS projects can make up for this investment. The LSS projects studied in this paper showed great potential not only for realizing directly visible benefits but also for continuous process improvement and thus increasing process cost reductions.

In the construction business, process improvement is hardly a part of daily routines and process monitoring is often not a common activity. In the company studied in this research, there are only data available from projects that enable to assess, for example, total costs at the end of the project and not to compare the project's performance compared to other projects. Another example is that the amount of concrete used for a project is known, but the yearly amount of concrete used by the company is not known. This indicates that performance is not measured and assessed per process or business unit in a given period, but per project as a whole. The data that are present in the company therefore are not useful to assess process performance but only to assess project performance. To be able to continuously improve processes, a company should specifically define the kind of data that are required and gather the process data from several construction projects in which the process took place.

Current monitoring systems in construction are usually used for collecting specific construction project data, and, to a lesser extent, they are used to learn from mistakes and best practices. For example, client complaints are collected and the defects repaired, but these defects are not registered and used as a source for continuous learning. Monitoring systems are aimed at ensuring that the project is delivered within client specifications, instead of learning from mistakes and best practices for future process improvement, as is the case with LSS.

Designing and establishing these kinds of monitoring systems cost both time and money. In most LSS projects studied in this research, these monitoring systems were established at the end of the projects as improvement actions. These additional measures required to perform LSS projects might result in higher costs of introducing LSS compared to other businesses, which could be a reason for companies to encounter problems when introducing the LSS DMAIC framework. However, to compete in today's construction industry, continuous process improvement (and thus process monitoring) will become of increasing importance in daily routines, irrespective of the use of LSS or any other process improvement method.

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Further reading

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