Generic Lean Six Sigma project definitions for the construction industry

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Abstract: Fuelled by an increased level of competitiveness in the construction industry, construction companies must continuously improve their processes to ensure high-quality and reliable products at low cost. The purpose of this paper is to support in defining Lean Six Sigma (LSS) projects in this industry. On the basis of our sample of LSS projects, we structured and analysed generic project definitions elements. We identified seven generic project definition templates. The templates include critical-to-quality (CTQ) flowdown models and operational definitions of each CTQ. With these templates, practitioners with local knowledge of their business are able to effectively define improvement projects. This paper presents the concepts of an effective project definition in the form of actionable knowledge that facilitates project leaders throughout the construction industry, and may form an initial of typical generic improvement projects for this industry.

Keywords: lean; Six Sigma; process improvement; problem structuring; problem solving.

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1 Introduction

Since clients are increasingly demanding high-quality and reliable products at low cost, and the construction industry faces an increased competitiveness caused by globalisation 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). Their study suggests that this development, in part, can be achieved by learning how to increase efficiency and productivity through process improvement.

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: LSS (see, for example, De Mast et al. (2012)).

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 organisation, and should be optimised as a whole. This optimisation is realised by improving the capacity, reliability and responsiveness of each step of the value stream, in order for these steps to be synchronised to create an uninterrupted flow of process steps, which is in line with customer demands and wishes (Jones, 2003; Womack, 2005). Since lean is focused on the entire value stream to be able to realise 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 to a project. Six Sigma is focused primarily on process variation reduction. Since 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 realise a process that is as predictable as can be on all factors that drive customer satisfaction (Hahn et al., 1999). Increasing predictability can be realised 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, since 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 is 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.

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 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 differs too much for these proven techniques to be useful or applicable to their processes. Because of this reluctance, only a few construction firms are known to use LSS, which, in turn, means there is very little literature available on such use.

In previous studies concerning LSS in the construction industry (see Van den Bos et al., 2014), several causes for long LSS project throughput times were found. Many of these are well known in project management literature (see Winch, 2010), such as existence of a project planning, the priority given to the project and commitment of project team members. Furthermore, from the study on LSS in the construction industry, we learned that the project definition is a crucial part of the success of a project. The importance of a clear definition and objective of a project and the metrics that need to be improved to achieve this objective is also pinpointed in the literature (Zu et al., 2008; Linderman et al., 2003; Lynch et al., 2003; Partington, 1996; Morris and Hough, 1987). A remedy suggested in the literature is to offer generic LSS project definitions to project leaders that are tested in practice (see, for example, Lokkerbol et al. (2012b), Niemeijer et al. (2011) and De Koning et al. (2008, 2010)). In this paper, we provide such generic LSS project definitions for project leaders in the construction industry.

The paper is structured as follows: In Section 2, we present a model to define LSS projects and present the dataset that was used for this research. In Section 3, we present the seven generic LSS project definition templates for the construction industry, based on our sample of 65 improvement projects. In Section 4, we present a CTQ-flowdown and the operational definitions per CTQ for each category of the generic project definitions, and we discuss real-life examples. Section 5 concludes and describes the contributions and potential impacts of our research.

2 Background of LSS project definition and research methodology

A model that helps to define the project's objective and to generate corresponding metrics is the CTQ-flowdown (see De Mast et al., 2012; De Koning and De Mast, 2007). The CTQ-flowdown links strategic focal point(s) to project objectives. In turn, each project objective is linked to and decomposed into CTQs. CTQs are then made operational in the form of measurements. The model thus links the strategic focal point(s) and each project objective to well-defined metrics that need to be improved to improve key business performance indicators. Furthermore, the project definition includes an operational definition for each CTQ, in order for a clear definition of each indicator to be measured in the measure phase of an LSS project (see Lokkerbol et al. (2012b) for an example of the use of these methods in the construction industry).

The data that we used to define the generic templates for the LSS project definition phase consists of a sample of 65 real-life LSS projects that took place in a Dutch construction company between 2003 and 2012. The projects represent typical LSS projects carried out by the company. The projects vary along several key dimensions, such as objective of the project (increase profit of sales, reduce operational cost and increase customer satisfaction), type of department (property development and residential building, non-residential building and infrastructure), type of process (tender, project execution and supporting services) and size (ranging from €54,000 to €640,000 worth of benefits).

To study generic elements in the CTQ-flowdowns of these projects, we were able to find a level that could be used to logically group some of these projects. Although every LSS project often has its unique CTQ-flowdown and operational definitions, many projects are comparable in terms of their project objective. As in Lokkerbol et al. (2012b), these objectives seem to be the right level of detail to group projects and systematically study the elements, i.e., performance indicators and CTQs, from the project definitions per group. Therefore, we were able to extract reusable and generic CTQ-flowdowns per group.

To construct the generic templates for LSS project definitions, we structured the projects by their project objective(s). During this step, we extracted the information that related to the project definition phase for each LSS project, i.e., the *strategic focal point(s)*, the *project objective(s)*, the *CTQs* and the *operational definition* of each CTQ.

Next, we structured the projects by the type of process in which the LSS project focused: project phases (tender, project execution, project handover, maintain and operate) or supporting services (finance, purchasing and customer service). Table 1 provides an overview of the areas in which LSS projects were executed and the number of projects in our sample per area or group.

Table 1 LSS project's focus on project objective and type of process

Group	*Tender*	*Project execution*	*Project handover*	*Maintain and operate*	*Purchasing*	*Finance*	*Customer service*
No. projects in sample	7	20	11	6	12	4	5
Cost	x	x	x	x	x		x
Speed							x
Quality						x	
Dependability	x		x				x
Flexibility							

We then related the performance indicators per group to typical objectives of the construction company, which were based on operations management literature. According to Slack et al. (2014), there are five generic performance dimensions: cost, speed, quality (design quality), dependability (delivery quality) and flexibility (ability to adjust to variability in demand). As a result, we were able to define a generic project objective per group that related to generic performance indicators.

For each group of similar projects, the generic CTQ-flowdown templates were constructed, and for each CTQ-flowdown template constructed, operational definitions were defined based on the available measurement procedures.

Our research was performed within a single construction company and, therefore, our sample is not necessarily representative for the entire construction industry. However, the generic templates are only an initial overview, and can help project leaders to effectively spend their time on defining improvement project's objectives.

3 Data

We present the seven generic project definitions in this section. Then in Section 4, we present the generic templates for these project definitions, consisting of a CTQ-flowdown and the CTQ's operational definitions. These templates support project leaders in the project definition phase to overcome the potential problem of a wrong problem definition, which is mentioned as an important disturbance in Van den Bos et al. (2014).

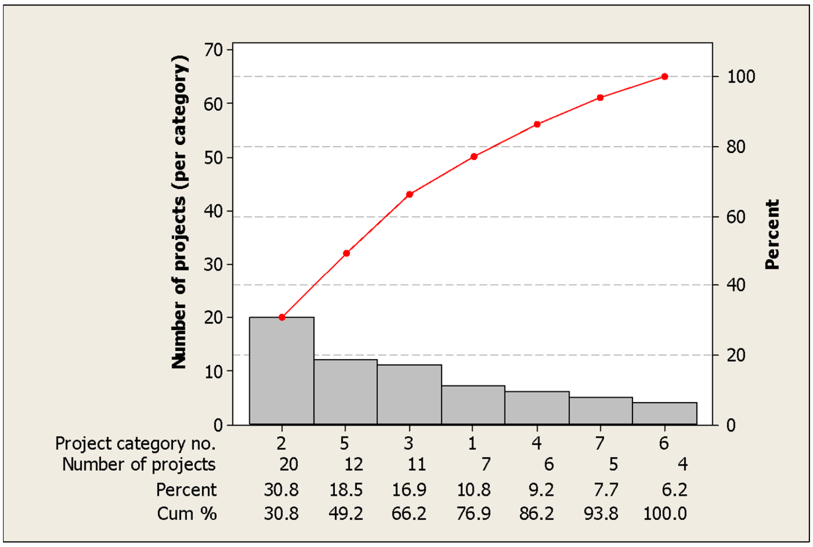
The templates serve project leaders executing projects both in project phases (tender, project execution, project handover, maintain and operate) and in supporting services (finance, purchasing and customer service).

We define the following seven generic project definition templates:

- increase profitability of sales by reducing cost of sales
- reduce operational cost by reducing realised costs
- increase customer satisfaction (and reduce cost) by reducing the number of defects on completion
- reduce costs by optimising cost of warranty claims and inspection
- reduce costs by reducing purchases and time to handle purchases
- increase profitability by reducing lost income
- increase customer satisfaction (and reduce cost) by improving the throughput time of delivery and the quality of complaints handled.

Figure 1 illustrates the Pareto chart, presenting the frequency of occurrence for each project definition template based on our sample of 65 projects. We see that Category 2) accounts for 30.8% of all projects, followed by Category 5) accounting for 18.5%, Category 3) accounting for 16.9% and Category 1) accounting for 10.8%. Cumulatively, these four project definition categories account for more than 75% of all projects that are used in this research. Categories 4, 6 and 7 account for 9.2, 7.7 and 6.2% of the projects in our sample, respectively.

Figure 1 Pareto chart of LSS construction project definitions (see online version for colours)



4 Generic templates for LSS project definition in the construction industry

In this section, we present the CTQ-flowdown and the operational definitions for each generic template. Also, for each template we present an example of a real-life project as it was executed at the company where our data was collected.

4.1 Increase profitability of sales by increasing profit of sales or reducing cost of sales

Projects in the first segment aim at increasing the profitability in a tender phase of a construction deal. In this phase, the one typically negotiates prices and spends time to quantify the budgets for the construction work and engineering (referred to as calculations). The CTQ-flowdown template discerns two main directions to focus on a project, namely:

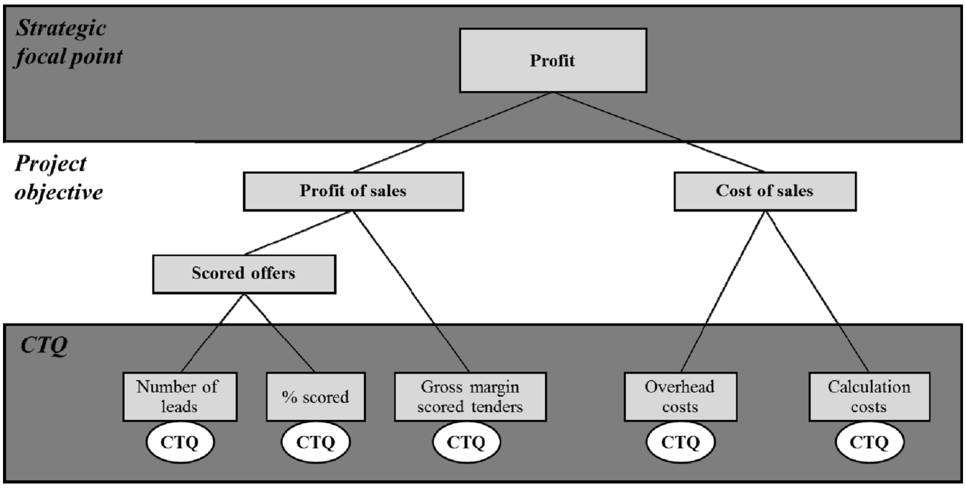
- increase the profit of sales generated in the tender process, by:
  - identifying more prospect tenders, called leads
  - improving the rate of tenders scored
  - improving the gross margin of scored tenders.
- reduce the cost of sales in the tender process, i.e., costs for calculations and corporate overhead generated in the tender process.

Figure 2 structures these project objectives and corresponding CTQs. The operational definitions needed to measure the CTQs are displayed in Table 2. The operational definition of a CTQ consists of three elements. First, the entity per which the CTQ is measured is specified. This entity is called the (experimental) unit. The number of leads and the percentage of offers scored are measured per month or quarterly. Similarly, the overhead and calculation costs are measured per tender. Gross margin is measured per scored project. Second, a measurement procedure for the CTQs is specified. The CTQs number of leads, percentage (of the number of leads) scored and the gross margin can be measured from sales documents. Costs for the calculations and corporate overhead are measured with the help of the documentation that is used to record information during a tender process. Third, the operational definitions report the goal (or direction) for the CTQ to reach the overall project objective.

Table 2 Operational definitions for projects increasing profitability of sales by reducing cost of sales

CTQ	*Number of leads/ % offers scored*	*Gross margin*	*Overhead and calculation costs*
Unit	Per month or quarter	Per scored project	Per tender
Measurement procedure	Sales documents	Project documents	Tender documents
Goal	As much/large as possible	As large as possible	As low as possible

Figure 2 A CTQ-flowdown for projects that increase profitability of sales by increasing profit of sales and/or reducing cost of sales



Example 4.1: One of the projects in this category focused on the tender process for the construction of non-residential buildings. More specifically, it aimed to increase the profits by increasing the success rate of a tender (i.e., the percentage scored), and by reducing the calculation costs. The Green Belt decided to select the percentage scored, internal and external cost for the calculations, and gross margin as CTQs. In addition, the throughput time of the calculations was measured as an important influence factor in this process. The Green Belt collected data from 13 tenders over the course of two years.

4.2 Reduce operational cost by reducing realised costs

The second template is the one frequently used among the projects in our sample. It aims to reduce the costs of the actual construction process by reducing the realised costs, since, in construction industry projects, there is a tendency for realised costs to often exceed budgeted costs during a construction project.

The realised costs (for construction) are unravelled into the important drivers of the costs in the actual construction process, namely labour costs (in man hours) and other costs. For example, the labour costs in man hours are split into productive hours and non-productive hours. The reason for this is because it is generally known that, in practice, the non-productive hours result from all kinds of inefficiencies and disturbances in the actual construction process, such as waiting for materials required. The other costs include costs for the machinery and facilities and material costs.

Figure 3 depicts these relations and the four CTQs in this category. The operational definitions needed to measure the CTQs are shown in Table 3.

Figure 3 A CTQ-flowdown for projects that reduce operational cost by reducing realised costs

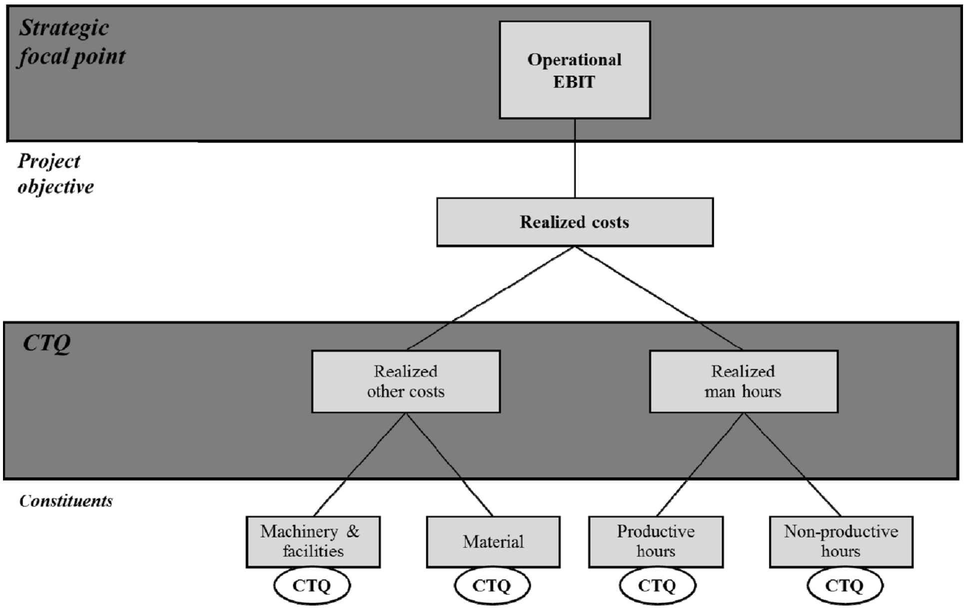


Table 3 Operational definitions for project reducing operational costs by reducing realised costs

CTQ	*Machinery and facilities costs*	*Material costs*	*Productive hours*	*Non-productive hours*
Unit	Per job or project	Per job or project	Per job or project	Per job or project
Measurement procedure	Project calculation/ registration	Project calculation/ registration	Project calculation, recorded man hours	Recorded man hours
Goal	As low as possible	As low as possible	As high as possible	As low as possible

Example 4.2: One project focused on the productivity per man hour in the process of constructing residential buildings. First, it looked at the result of man hours spent (also with respect to the budgeted man hours in the calculations). Second, the ratio of productive vs. non-productive hours was determined. To gather the required data, an external consultant was hired to execute a work-sample study. This study provided the measurements to assess the performance of the process.

4.3 Increase customer satisfaction (and reduce cost) by reducing the number of defects on handover

Around the completion date of a building project, the customer performs a deliberate inspection together with one of the project managers to check whether the project meets all specifications. During the round(s) of inspections, the project manager records all kinds of defects, or shortcomings, mentioned by the customer. The number of defects is an important driver for the overall quality of the product (and thus for the customer's satisfaction), and at the same time, these defects drive the cost of this handover process since each defect requires extra time and effort to resolve.

The total cost of handover results from the cost per defect to be resolved and the total number of defects. The number of defects as well as the time needed to resolve a defect are important drivers for the total quality of the product. Both factors can have a serious impact on the customer satisfaction.

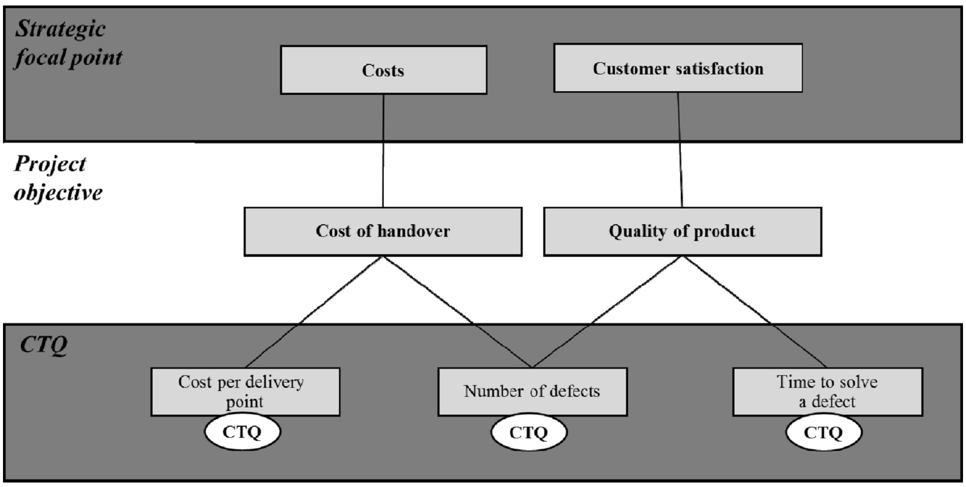
The relationship between the strategic focal point(s) and CTQs is shown by the CTQ-flowdown depicted in Figure 4. Table 4 illustrates the operational definitions of these CTQs.

Example 4.3: In this category, one improvement project focused on reducing the amount of defects/shortcomings in the handover of infrastructure projects. On a yearly basis, over 11,000 defects are registered within this department. More precisely, this project focused on the so-called Integrated Projects, which represents 30% of the department's revenue. The project leader identified only one CTQ, i.e., the number of defects. Since the number of defects is strongly related to the size of a (infrastructure) project, he decided not to measure the number of defects per project but per million euros revenue. Note that this project is not attempting to reduce the cost of defects. The main focus is on improving customer satisfaction instead of reducing internal costs.

Table 4 Operational definitions for projects increasing customer satisfaction (and reducing cost) by reducing the number of defects on handover

CTQ	*Cost per defect*	*Number of defects*	*Time to resolve a defect*
Unit	Per defect	Per product/project	Per defect
Measurement procedure	List of defects/ shortcomings	List of defects/ shortcomings	List of defects/ shortcomings
Goal	As low as possible	As low as possible	As short as possible

Figure 4 A CTQ-flowdown for projects increasing customer satisfaction (and reducing cost) by reducing the number of defects on handover



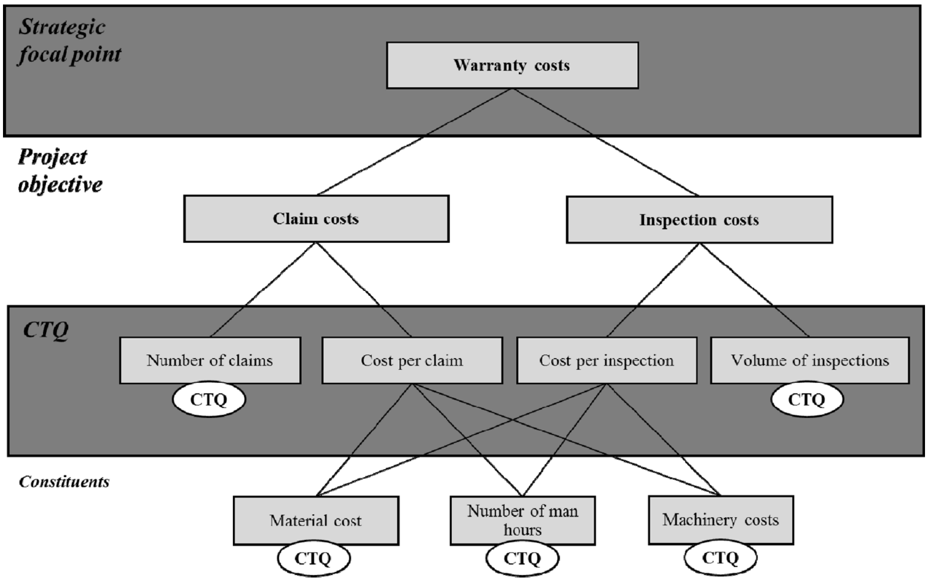
4.4 Reduce costs by optimising cost of warranty claims and inspection

In today's competitive environment in the construction industry, one sees an increased power of customers that yields to enhanced warranty components in the products of a construction company. The concept of warranties involves a shift of the burden of the construction's quality control and maintenance from the owner to the contractor (Thompson et al., 2002). These expected benefits for the customers, however, leave the contractor with an open question on how to deal with these costs. The contractor is to find a cost-effective balance between potentially higher costs in terms of inspection and maintenance, and the expected claim costs yielding from the customer's warranty claims.

In downward direction, the cost of a claim is driven by the number of claims and the cost per claim, which depends on the material costs and man hours that are needed to handle and resolve the claim. The inspection cost is driven by the volume of inspections and the cost per inspection, which again depends on the material costs and man hours that are needed to execute a round of maintenance or repair.

Figure 5 depicts these relationships between cost types and CTQs. The operational definitions needed to measure the CTQs are shown in Table 5.

Figure 5 A CTQ-flowdown for projects reducing cost by optimising cost of warranty claims and inspection



Example 4.4: The project that serves as an example focused on reducing warranty costs in the infrastructure department. The project leader identified CTQs concerning the number of claims, costs of maintenance, inspections, claims and the amount of materials and equipment used in dealing with claims and maintenance activities. Since maintenance activities on warranty basis are relatively new to the construction industry, this project aimed to gain a good understanding on the main cost drivers in the process as well as optimising the process as a whole.

Table 5 Operational definitions for projects reducing cost by optimising cost of warranty claims and inspections

CTQ	*Number of claims*	*Material/ machinery cost*	*Number of man hours*	*Volume of inspections*
Unit	Per month or year	Per claim/ inspection	Per claim/ inspection	Per warranty contract
Measurement procedure	Legal department	Recorded expenses	Recorded man hours	Warranty contract agreements
Goal	As low as possible	As low as possible	As low as possible	As low as possible

4.5 Reduce costs by reducing purchases and time to handle purchases

Similar to projects in financial services (Lokkerbol et al., 2012a) and healthcare (Niemeijer et al., 2011), also within the (financial) supportive department of a construction company, there are projects defined that aim to reduce the amount of lost income. At the same time, and as illustrated in Figure 7, these projects may focus on the reduction of the expenses, especially expenses that were not included in any construction project's calculations, prior to the project. CTQs for these kinds of processes are the time to place an order or to handle a delivery, or the processing time of an invoice. Other CTQs are the number of purchases and the purchase price and terms. The CTQ-flowdown is shown in Figure 6; the operational definitions of the CTQs are shown in Table 6.

Figure 6 A CTQ-flowdown for projects reducing costs by reducing purchases and time to handle purchases

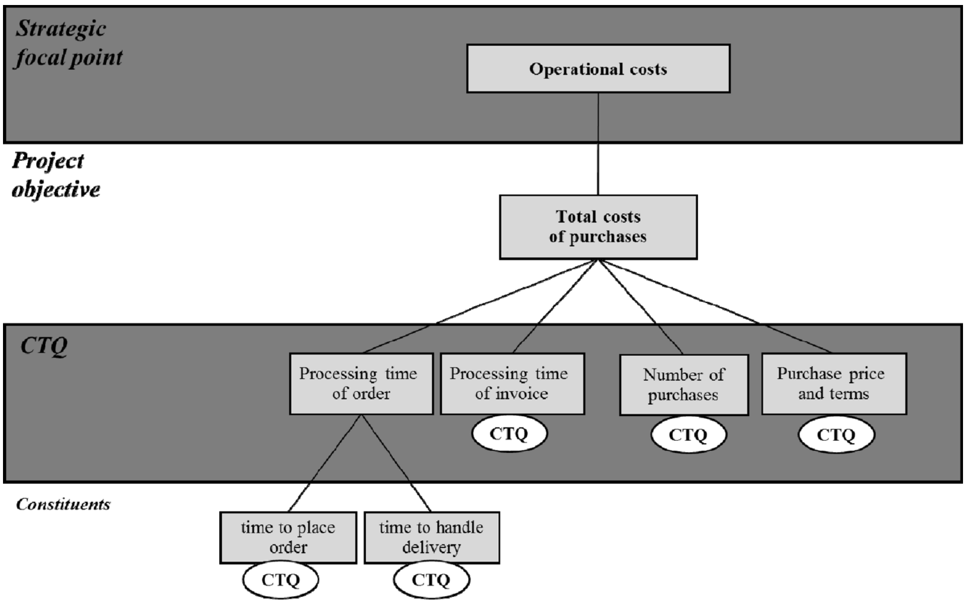


Table 6 Operational definition for projects reducing costs by reducing purchases and time to handle purchases

CTQ	*Time to place order/handle delivery/process invoice*	*Number of purchases*	*Purchase price and terms*
Unit	Per invoice/ order	Per week, per supplier	Per warranty contract
Measurement procedure	Financial recordings, invoice registrations	Financial recording, invoice registrations	Project contract specifications
Goal	As short as possible	As low as possible	As 'positive' as possible

Example 4.5: The project in this example focused on reducing the cost of the process of order until delivery to the construction site. Every week, several orders were placed and a supplier delivered the ordered goods directly. This resulted in un-coordinated purchases, the delivery of small batches and high costs of delivered goods. The CTQs in this project were the number of orders and deliveries per week, per supplier, per project. The benefits of this project were high cost reductions owing to coordinated purchasing, which was achieved by establishing less deliveries and larger batches per delivery.

4.6 Increase profitability by reducing lost income

The following category is focused on the increase in income, since, also within the financial supportive department of a construction company, one aims to reduce the amount of lost income. In most cases, a project leader may define both yearly (or quarterly) revenues and the missed payments as CTQs. The focus will then be on lost income, and the revenues are taken as fixed (i.e., we will not aim at increasing net income by increasing revenues). Figure 7 depicts the generic flowdown for this category. Table 7 states the operational definitions.

Figure 7 A CTQ-flowdown for projects increasing profitability by reducing lost income

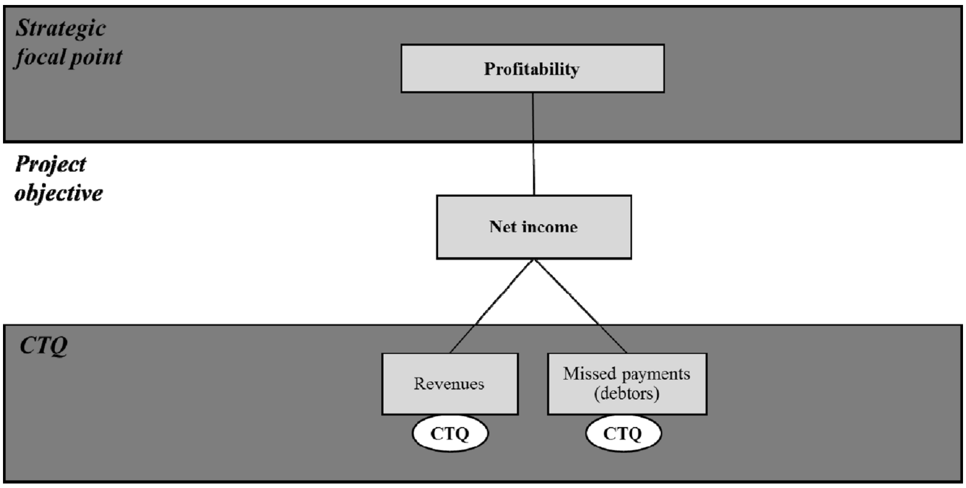


Table 7 Operational definitions for projects increasing profitability by reducing lost income

CTQ	*Revenues*	*Missed payments (debtors)*
Unit	Per invoice/project	Per debtor's account
Measurement procedure	Financial recordings, invoice registrations	Financial recording, invoice registrations
Goal	As high as possible	As few as possible

Example 4.6: In this category, a project was focused on improving the cashflow of the service and maintenance department. The CTQ that was improved was the difference in cashflow between the amount billed and the amount received. This CTQ was measured in 'cashflow *percentage* per period'. Note that this project was not focused on increasing revenues, but solely on reducing the gap between the amount of cash billed and received, or reducing missed payments.

4.7 Increase customer satisfaction (and reduce cost) by improving the throughput time of delivery and the quality of complaints handled

The next template refers to both the construction process, in terms of the throughput time of delivering a construction project, and the supportive process, in terms of handling complaints at a customer service department. Contrary to the previous category, this category is aimed mainly at enhancing customer satisfaction.

The time to construct a building is seen as an important indicator for processes in the construction industry (see Egan, 1998). The construction time, which is referred to as the throughput time of a construction project, for offices, roads and houses, is currently expected to be reduced with 10–15% per year.

Since reduction of the time to handle a complaint or request also will result in lower cost per complaint/request handled, both customer satisfaction and operational cost are often strategic objectives of improvement projects in this category. Important CTQs are the processing and waiting time to handle a complaint or request. More important for the client relationship, however, is the additional time required for rework. This CTQ determines the quality of the solution offered to a client, since the relationship will most likely be affected if a solution is not satisfactory the first time.

Other important CTQs that affect the operational cost are the number of complaints/requests and cost that are incurred in solving these. Figure 8 depicts the relation between CTQs and strategic focal point. Table 8 states the operational definitions of CTQs.

Example 4.7: One project focused on enhancing the efficiency and effectiveness of complaint handled and improving the appreciation of clients after handover of the project. The number of complaints was measured per week based on the number of registered complaints and the number of outstanding complaints at the end of the week.

Another project had the throughput time of the construction delivery process as a focus. It was found that part of the delays can be reduced with an early check on small defects (rework), such as scratches in glass or paint.

Figure 8 Increase customer satisfaction (and reduce cost) by improving the throughput time of delivery and the quality of complaints handled

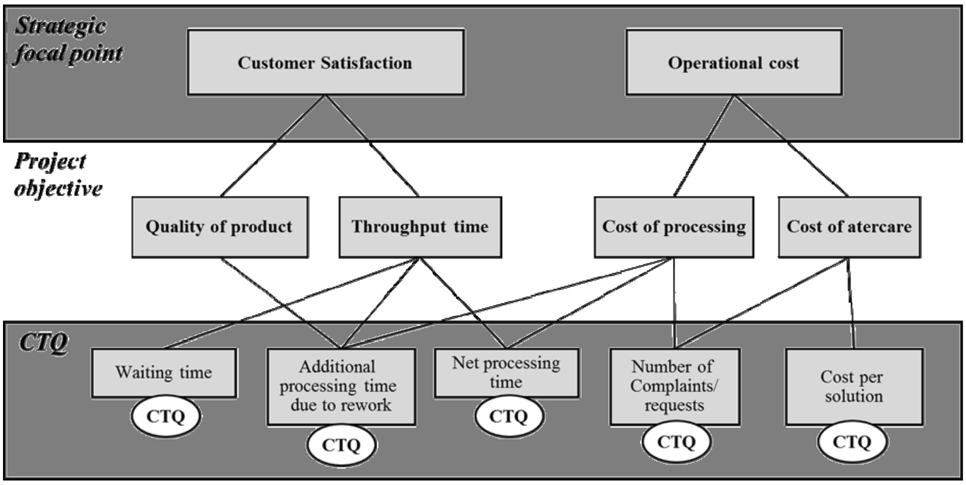


Table 8 Operational definitions for projects increasing customer satisfaction (and reducing cost) by improving complaints handled

CTQ	*Processing time/ waiting time*	*Additional processing time*	*Number of complaints*	*Cost per solution*
Unit	Per complaint, per project	Per complaint, per project	Per week, or per project	Per complaint
Measurement procedure	Registrations from database	Registrations from database	Registrations from database	Registrations from database
Goal	As low as possible	As low as possible	As low as possible	As low as possible

5 Conclusions and discussion

LSS as a process improvement method was hardly used in the construction industry at the time when the first projects of our sample started in 2003. This fact makes it interesting to assess the use of this method in the construction industry. Our analysis of 65 LSS improvement projects gives valuable insight in the process of defining and executing improvement projects in the Dutch construction industry.

The generic project definition templates that follow from our study assist LSS project leaders in the construction industry when dealing with issues during the project definition phase, such as problem structuring. These templates serve project leaders, often with in-depth process knowledge, to effectively define an LSS project and may form an initial overview of generic improvement projects for this industry.

Our research has some limitations. The sample is not representative for the construction industry as a whole since the sample represents LSS projects that are executed at one single Dutch construction company. The project objectives are in line with the mission statements of the construction company that we studied and are, therefore, limited to this strategic environment. Also, the projects in our study cover four of the five generic performance dimensions that are common in the operations management literature (cost, speed, quality, dependability and flexibility). Therefore, our sample may be incomplete.

Our generic templates are neither intended as a basis for strong claims about which types of improvement projects should be executed by a construction company, nor do we claim to present a complete overview. However, we propose the templates as best practices, represented in our case base, and as a source of valuable knowledge in it. We suggest to theoretically validate the templates in the near future, when more project data are available from several construction companies of various geographies.

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