

Application of Lean Six Sigma to a panel equipment manufacturer

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In this paper, we apply the Lean Six Sigma (LSS) approach to demonstrate the continuous improvement in forecasting the manufacturing costs for a flat panel display equipment manufacturer. Soft systems methodology (SSM) was selected as a tool and applied to the improvement phase of the LSS approach, as it is a problem-solving methodology that is suitable for complex problems. A very important aspect of SSM is its reliance on being a participative process where knowledge and resultants can only be gained through debate. The purpose of the debate is finding a compromise that everyone can accept. The results show that the application of LSS approach with SSM effectively improves the supportive activities as well as the manufacturing processes.

Keywords: Lean Six Sigma; soft systems methodology; supportive activity

Introduction

In recent years, the terms Six Sigma and Lean thinking, called Lean Six Sigma (LSS), were combined to emphasise the quality and service improvement process offered by Six Sigma and the productivity and cost reduction tools offered by Lean thinking. When we surveyed the application of the LSS approach, we found that most researches usually focused on the process improvement of manufacturing spots and seldom discussed its business performance. For instance, in the flat panel display (FPD) equipment-manufacturing industry, the business model is similar to the manufacturing industry model but different from the engineering industry model in terms of product characteristics. The major concern of the business model is its capability in holding up against competitors. Both profits and contracts of a company depend on the accuracy of forecasting costs. In the past, the quotation cost was based on a project team's projection of forecasting costs; the team did not include the historical data due to customers' customisation of the FPD equipment. Thus, the variation in forecasting costs is quite unstable. If the forecasted costs exceed the actual costs, then business contacts will be lost. On the other hand, if the forecasted costs are less than the actual costs, less time will be available for project completion. That is, this kind of supportive activity is an important task and an integral part of the FPD equipment-manufacturing industry.

LSS is a business improvement methodology that maximises shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital. Most applications of LSS used in the improvement phase

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rely on psychological brainstorming or statistical tools such as design of experiments, setup reduction, queuing methods, and 5S. No systematic method is used in the improvement phase of LSS. Soft systems methodology (SSM) is a way of 'systems thinking' that helps us understand the various perceptions that exist in the minds of different people involved in a complex management system; it seeks to evaluate as many different options as possible (Checkland & Scholes, 1990). We discuss as to how to integrate SSM into the improvement phase of the LSS approach to demonstrate the improvement in the supportive activities of a FPD equipment manufacturer.

The rest of this paper is organised as follows: the second section reviews the associated researches on LSS and SSM. The third section proposes that SSM can be integrated into the improvement phase of LSS. The fourth section presents a case study to show the improvement performance on supportive activities. The final section presents the conclusion and future research.

Literature review

An increasing number of manufacturing companies are choosing to employ quality programmes to improve their manufacturing performance. By focusing on the performance of a product, the companies gain procedure experience. After using such quality programmes over time, product and service quality as well as lower rejection costs should be attained. In the past, process improvement has been achieved by using problem-solving techniques such as the total quality tools and classic statistical analysis, business process reengineering and total productive maintenance (Wiklund & Wiklund, 1999) and by integrating Six Sigma and theory of constraints (Ehie & Sheu, 2005). In addition, Lean thinking has been successfully considered to improve firm performance through elimination of waste (Womack & Jones, 1996). Lean thinking is also defining value for the customers, focusing on adding value, driving out wastes, reducing cycle times, and ensuring smooth flow of work at the pull of the customers (Bicheno, 2000).

The Six Sigma methodology as an improvement programme has received considerable attention in the last few years. Montgomery (2005) identified three generations of Six Sigma: Generation I (1987–1994), which focused on reduction of defects; Generation II (1995–2000), which focused on cost reduction; and Generation III (after 2000), which is currently focusing on enterprise value. A successful Generation III enterprise does not stop the activities of Generations I and II, but it builds on them; it will require the deployment of new methods and techniques to address service and commercial business processes and transactional system qualities. In the past, Six Sigma and the principles behind the Lean thinking have often seemed more like competitors than co-conspirators. In recent years, a powerful action plan for dramatically improving quality, increasing speed, and reducing waste has been a general outline of the LSS approach.

Arnheiter and Maleyeff (2005) suggested that an LSS organisation would capitalise on the strengths of both Lean management and Six Sigma. Pickrell, Lyons, and Shaver (2005) presented two case studies for LSS projects completed at a worldwide manufacturer of precision slip ring and integrated motion systems for high-performance requirements in military and commercial aircraft, satellites and space vehicles, missiles, and automated industrial machinery. The results show that the LSS approach can reduce the costs, cycle time, customer returns and inventory and increase the production capacity. Furterer and Elshennawy (2005) presented a case study of applying the LSS tools and principles to improve the quality and timeliness of a city's Finance Department. After the implementation of an LSS programme, the time to process payroll, purchase and accounts payable

were reduced by 60%, 40%, and 87%, respectively. Van den Heuvel, Ronald, Does, and de Koning (2006) stated that the major challenges that hospitals faced were from patients who continuously demanded for quality care to be improved and from health insurance companies that demanded the lowest possible prices. They applied the LSS programme to help healthcare providers achieve these conflicting goals. de Koning, Verver, van den Heuvel, Bisgaard, and Does (2006) illustrated how principles of Lean thinking and Six Sigma can be combined to provide an effective framework for producing systematic innovation efforts in the healthcare industry. Kumar, Antony, Singh, Tiwari, and Perry (2006) proposed an LSS framework to reduce the defect in the final automobile accessories manufactured by a die-casting process. The optimal settings of the process parameters have been improved in the die-casting process by over 12%. Dahlgaard and Dahlgaard-Park (2006) provided the roadmaps of total quality management, lean production and six sigma quality. They suggested that the LSS approach should focus on understanding the human factor and the needed corporate culture. Gras and Philippe (2007) provided a review of the application of the Six Sigma concept in the healthcare industry. Byrne, Lubowe, and Blitz (2007) presented that LSS could lead to product innovations, such as Caterpillar's phenomenally successful low-emission diesel engine, and also to redesigned processes, including a streamlined supply chain. After 5 years, by 2005, revenues at Caterpillar had grown by 80%. Thomas, Barton, and Chuke-Okafor (2009) proposed an integrated LSS model for small-medium enterprises in a manufacturing industry. Carleysmith, Dufton, and Altria (2009) provided a case study to demonstrate how LSS can be used successfully to improve the development of new pharmaceutical manufacturing processes. They also discussed the tools, barriers, and benefits for the implementation of LSS.

SSM was developed to analyse and describe the relevant aspects of the human activity system and how it interacts with the technology system (Smyth & Checkland, 1976). Checkland and Scholes (1990) reported that there are several successful applications of SSM in the healthcare industry. Lehaney and Paul (1996) applied SSM as a tool to aid in activity identification for a simulation model of out-patient services at Watford General Hospital. Checkland (1998) reported that SSM is particularly suited to complex management systems, seeking to evaluate as many different options as possible. This approach is applicable to many domains, to which change management, planning for business systems, information systems planning, human resource management, analysis of logistics systems, and expert systems development belong. Delbridge (2008) investigated an application of SSM in a library and information service context. The SSM was found to provide a useful basis for the identification activities that a library management system should support.

LSS with SSM

No matter what the approach is for deploying improvements within a company, having a standard improvement model such as DMAIC (define, measure, analyse, improve and control) is extremely helpful, because it provides the company with an improvement roadmap. Generally, after a project's definition phase, key process characteristics are identified and benchmarked in the measure and analyse phases; then this is followed by the improvement phase, where a process is modified for better performance, and the control phase aims to monitor and sustain the gains. Thus, we propose a DMAIC model based on LSS and SSM to improve the performance of supportive activity (Figure 1).

The basic elements and key tools in the DMAIC model are as follows.

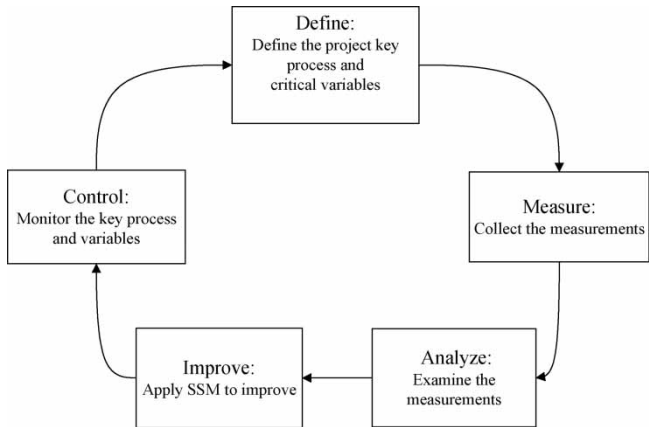


Figure 1. An improvement model for supportive activities.

In the define phase, a team and its sponsors reach an agreement on what the project is and what it should accomplish. They should establish some metrics to measure the success of the project, such as customer satisfaction, speed or lead time, sigma level improvement, and financial outcomes. In order to accomplish the objectives of this step, a common tool called SIPOC is used to help in confirming or refining project scope and boundaries. An SIPOC diagram includes Suppliers, Inputs, Process, Outputs, and Customers for creating a high-level map of process. Supplier – the entities that provide whatever is worked on in the process. The supplier may be an outside vendor or another division or a coworker. Input – the information or material provided. Process – the steps used to transfer (both those that add value and those that do not add value). Output – the product, service, or information being sent to the customer (preferably emphasising critical to quality features). Customers – the next step in the process or the final customers. A core principle of LSS is that defects relate to anything that makes a customer unhappy, such as long lead time, poor quality, or high cost. To address any of these problems, the first step is to take a process view of how the company goes about satisfying a particular customer requirement.

In the measure phase, the performance standard of the process is verified and established to obtain a baseline for future improvements. One of the major advances of LSS is its demand for data-driven management. Most of the other problem-solving methodologies tended to dive from identifying a project in the improvement phase without sufficient data to really understand the underlying causes of the problem. A service process tries to improve that the process spends a great deal of its time dealing with data problems. There are a lot of measure tools that include everything from data collection to brainstorming methods and prioritising tools. Some of the most common tools are process description tools (value stream maps, process cycle efficiency, and time value analysis), focus/prioritisation tools (failure mode effect analysis and Pareto), data collection, and quantifying and describing variation (control charts).

The purpose of the analyse phase is to make sense of all information and data collection in the measure phase and to use that data to confirm the source of delays, waste, and poor quality. The most common tools used in the analyse phase are those used to map out and explore cause and effect relationships such as the 5 ‘whys’ analysis, cause and effect diagrams, and scatter plots. One of the major themes of LSS is that slow processes are expensive processes. Value stream mapping analysis is also a key tool for a team to

identify the hidden time traps and to find out the root causes that hinder the achievement of a substantial increase in value-added time in process.

The purpose of the improvement phase is to make changes in a process that will eliminate the defects, waste, costs, etc. Common tools are those, such as solution matrices, that link brainstormed solution alternatives to customer needs and the project purpose. Many of the Lean tools play their most important role in the improvement phase, for instance, pull system, setup reduction, queuing methods for reducing congestion and delays, and the 5 'whys'. Here, we adopt SSM to improve the performance, and the seven stages of SSM are as follows:

Stage 1: Obtaining an idea about the problem situation. The purpose of this stage is not to recognise a definition to a problem, but rather to obtain a vague and unstructured idea of the parameters and structure of a problem. Through this, a range of relevant choices can be made.

Stage 2: Expressing the problem situation. The relationship between an organisation's structure and process should illustrate the problems, tasks, and elements of the environment in a clear and cohesive manner. A rich picture can be used to identify relevant themes for sharing different perspectives and be a basis for further discussion.

Stage 3: Formulating the root definition of relevant purposeful activity system. The root definition defines what is relevant to the system and also people who might either influence or be influenced by the system. The mnemonic model called CATWOE should be used to construct root definitions. CATWOE stands for Customer: people affected by the system; Actor: people performing activities in the system; Transformation: the transformation carried out by the system; Weltanschauung: the 'world-view' or viewpoints held of the system; Owners: the person(s) with the authority to decide how (and if) the system will be carried; and Environment: the larger system within which the system under consideration exists and operates. The root definition and CATWOE provide the analyst with a framework that ensures consideration of all the different viewpoints.

Stage 4: Building conceptual models of relevant systems named in root definitions. The conceptual models are based only on the agreed root definitions of the desired system. This stage prepares the participants for discussions that will take place in 'the real world'.

Stage 5: Comparing the models with real-world actions. The conceptual models constructed in Stage 4 give structure to a meaningful and coherent debate about the problem situation. It surfaces a wide range of questions, highlighting the differences between perception and reality. The discussion around this model(s) provides an opportunity for participants to rethink their assumptions. It also allows them to discuss changes that could bring about an improvement in the problem situation. This discussion leads to Stage 6.

Stage 6: Determining desirable and feasible changes. The aim of this stage is to identify and explore changes that are systemically desirable and culturally feasible. Checkland (1999) described three kinds of changes: structural, procedural, and attitudinal. Structural changes refer to organisational groupings, reporting structures, or structures of functional responsibilities. Procedural changes include all the activities that go on within the organisation, such as operational processes and reporting conventions. Attitudinal changes refer to changes in the expectations that people have of the behaviour of other actors as well as changes in their readiness to categorise certain kinds of behaviours as either bad or good.

Stage 7: Taking action to improve the problem situation. This stage seeks to solidify commitment and responsibility in order to formulate an action plan. The implementation steps include the following: who is to take action; what kinds of actions should be taken; where and when should the action be taken; timetables; resources; and a scope. In addition, attitudinal and behavioural changes need to be considered along with the impacts and effects on current systems.

The purpose of the control phase is to make sure that any gains made will be preserved, until and unless new knowledge and data show that there is an even better way of operating the process. There are some areas of control critical in service environments: making sure that the improved process is documented and turning results into dollars, maintenance of gains is verified down the road, an automatic monitoring system that will ensure that an 'out of control' situation is installed, implementation is piloted, and a control plan is developed. Control chart is one of the key control tools. Mistake prevention and mistake proofing are also very helpful and closely related concepts in the control phase.

Case study

In this research, the case study is a practical project that involves the improvement of manufacturing cost forecasting accuracy. A representative mechanic company supplies the FPD equipment assembly; the FPD equipment is supplied to a representative mechanic company. This case company called company-A is a leading provider of FPD equipment assembly business in Taiwan and Mainland China. In the FPD equipment-manufacturing industry, the major function of the business model is to attract more consumers. The profits from the business depend on the forecasting accuracy. For nearly 5 years, company-A has provided efficient equipment to both local Taiwanese companies and foreign companies. With over 600 employees in Taiwan and Mainland China, company-A adopted a strategic plan 'to make services quick and on-time delivery for all customers'. In 2006, due to the hyper-competition in FPD equipment assembly business, the top management of company-A decided to further strengthen its competence of on-time delivery-based competition by utilising the LSS approach.

The functions of the DMAIC model for the forecasting cost project in this case study are as follows.

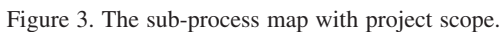
Three steps are involved in the define phase, and they are described below.

The define phase

Step 1: Selecting the project – according to the experience of company-A, it takes much longer time and resources to handle the forecasting process of manufacturing costs for some customers than for others who need additional time to prepare, check, and re-confirm. Consequently, the accuracy of forecasting manufacturing costs based on customers (benefits?) turns out to be much longer and less reliable. Thus, for better capital turnover efficiency, according to the voices of inner customers, the project title is identified as 'to reduce the variation of forecasting manufacturing costs'.

Step 2: Defining the project scope – based on step 1, the project team analyses the high-level process of SIPOC-related activities. It ensures that the team members are all reviewing the process in the same way. It also informs leadership of exactly what the team is working on. The process is mapped at a high level. Then working from the right, it identifies the customers, the outputs, the inputs, and the suppliers as shown in Figure 2. Based on the high-level process map, we set up the project scope in which the activity is either 'value added' or 'non-value added' as the circle area in the sub-process shown in Figure 3.

Step 3: Defining defects – according to the past experience, there is approximately a 40% cost difference between forecasted and actual costs in forecasting manufacturing cost activities for most customers. For project scope, the project team described 'more than 15% cost difference between the forecasted and actual manufacturing costs' as one defect in this case.



In the measure phase, the performance standard of the process is verified and established to obtain a baseline for future improvements. The two steps involved in the phase are as follows:

Step 2: Measuring as-is process capability – according to the individual control chart of the latest 180 samples (Figure 4), the result shows that this process is out of control. Thus, the current-state process capability is not available at this point. After the removal of all the control points, the process capability indices of Cp and Cpk are 0.78 and 0.64, respectively.

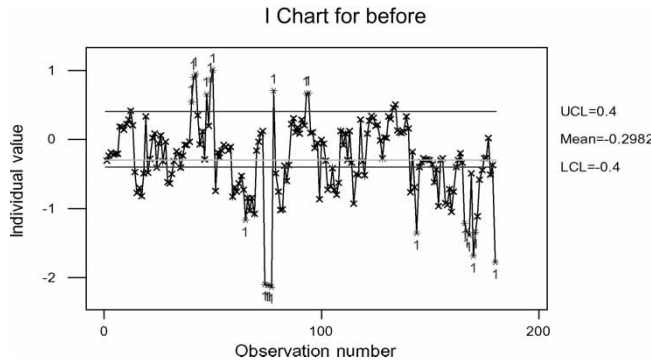


Figure 4. The individual chart of the samples before the project.

The analyse phase

In the analyse phase, the performance objective is defined and the key variation sources are identified. The three steps involved in the process are as follows:

Step 1: Identifying the root causes – the root causes of the problem of variation between the forecasted and actual costs are identified using one-way ANOVA and a Pareto diagram (Figure 5). According to one-way ANOVA, the p -value is 0.000 less than 0.05, showing that different products have different cost rates. The Pareto diagram illustrates that 80% of the problems are from 20% of the root causes.

Step 2: Using failure mode and effects analysis (FMEA) – the purpose of FMEA is to filter the factors that may cause the function failure with high risk priority number (RPN) in the key process in advance. The high number of the RPN, usually defined as greater than 125, is selected, and the recommended corrective actions are given in Table 1.

Step 3: Identifying the vital few initial variables – according to the one-way ANOVA and Pareto diagram depicted in Figure 5, the project team concluded that the vital few initial variables can be attributed to (1) the lack of setting up of the standard working hours by different product categories, (2) the lack of adding after service costs to the forecasted costs, (3) non-collection of the material costs after installation, (4) uncreated

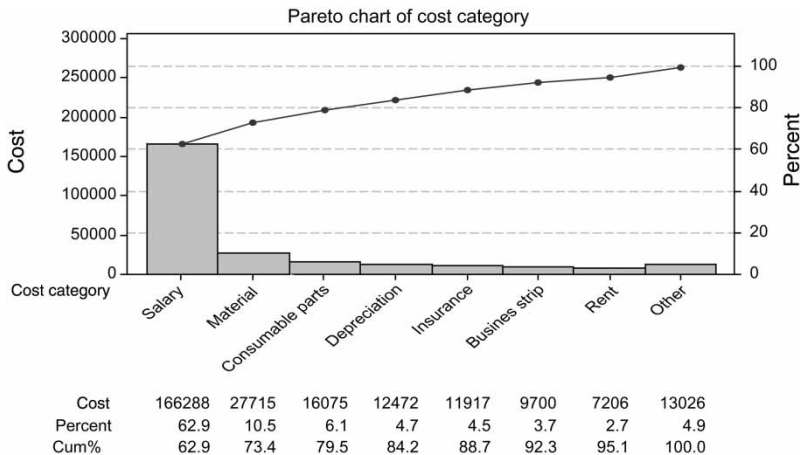


Figure 5. The root cause analysis based on Pareto diagram.

Table 1. FMEA for the key process.

Specific function(s) of process	Potential failure mode	Potential effects of failures	Severity	Potential causes of failure	Occurrence	Current process control	Detection	RPN	Recommended corrective action
Cost assessment	Code error	Cost items lost	7	Difficulty in forecasting	9	No control	9	567	Estimating based on a similar product
	Cost mistaken	Manufacture cost data missing	9	Lack of standard working hours	8	No control	9	648	Setting up of the standard working hours according to the product category
Labour hour and cost data entry	Data missing	Cost would not be collected	9	Human error	4	No control	10	360	Implementing a Barcode system
	Data incorrect	Delivery time overdue	8	Lengthy vendor lead time	6	Work order tracking sheet	6	288	Tracking of the production meeting
Cost application	Abnormal cost	Design changed	9	Material overpicking	8	Standard operation procedure	4	288	On-job training and error proofing
	Drawing mistake	Material overpicking	8	Design changed	8	Engineer changed request	8	512	Drawing review

contracts resulting from a contract that is not ready, and (5) delay resulting from equipment test procedure.

The improve phase using SSM

In the improve phase, improvement activities using SSM are proposed. The five steps involved in the phase are as follows:

Step 1: Developing solutions – based on the findings of the significant causes in the analyse phase, the solutions are proposed by project team members through seven-stage processes of SSM. First, the root definition establishes a procedural system for feeding concepts into the business model. Second, the CATWOE defines clients as business models; actors are cost-forecasting and control managers; transformation is required for the procedure and the department's objective; world-view is an objective-related concept that is necessary and feasible, using concepts that can be engineered; owners are project team members, including the sales department manager; environment is the corporate business objective and external information. Lastly, the conceptual model for this relevant system is built as shown in Figure 6.

Step 2: Implementing the improvement plan – after the solution development step, an improvement plan that includes improvement actions, respective in-charge departments, and introduction schedule is devised, which is given in Table 2.

According to the improved activities listed in Table 2, we selected a work order (#f06-0230) to demonstrate the differentiation as 0.2%, which before improvement was 37.6%. The differentiation based on the new method is as follows: (total actual costs – forecast costs)/(total actual costs), that is, (US\$39,342 – US\$39,263)/US\$39,342 = 0.2%; in

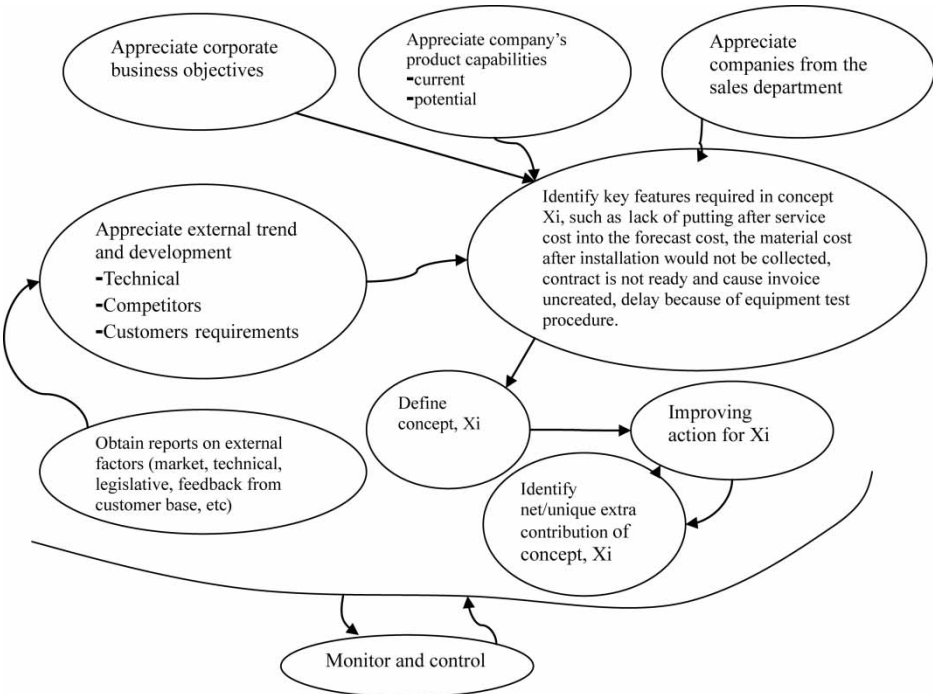


Figure 6. The conceptual model for forecasting manufacturing costs.

Table 2. The improvement plan of cost-forecasting activity.

Root causes	Improvement action	In-charge department	Schedule
Lack of setting up of the standard working hours by different product categories	Set up the product category and standard working hours accordingly	Sales	January 2007
Lack of adding after service cost to the forecasted cost	Modify the software and change the item code in the system	Finance	January 2007
Non-collection of the material cost after installation	Add the material cost to the total cost before project closed	Sales	January 2007
Contract that is not ready and results in invoice being uncreated	Extend contract, no goods' delivery without a contract	Sales	January 2007
Delay resulting from equipment test procedure	Set up the 'Standard Operational Procedure'	Sales and finance	January 2007

which, the forecast cost is US\$39,263 and the total actual cost is US\$39,342, which include the in-house manufacturing costs of US\$11,628, finished costs of US\$17,076, and extra costs after delivery of US\$10,638.

Step 3: Identifying the new process capability – after the progression of the improvement plan for approximately 6 months, the project team collects the latest 12 samples to calculate the new process capability in order to observe the improvement effectiveness. The results of the analysis show that the average differentiation has reduced dramatically from -29.8% to -0.0125% . Furthermore, the process capability indices of C_p and C_{pk} increase from 0.78 and 0.64 to 1.62 and 1.49, respectively.

Step 4: Comparing the differences before and after the implementation of the improvement plan – as shown in Table 3. The trend chart demonstrates that there is a tremendous progress after the implementation of the improvement plan as shown in Figure 7. Not only has the average differentiation rate been reduced, but the variance of costs of forecasting has also decreased.

Step 5: Establishing the 5S system – 5S (sort, store, shine, standardise, sustain) was developed by Toyota to eliminate the hidden factory waste. The implementation of the 5S system helped to organise the work environment, standardise the workflow, and assign clear ownership of processes to employees. It also helped in increasing the accuracy of data entry in the cost analysis.

Control phase

In the control phase, a robust control plan of risk management to prevent system failure is proposed. The project team uses a range of 1–9 possible points for possibility and

Table 3. The example of risk management in the control plan.

Risk causes	Possibility	Influence	Risk score	Prevention actions
Employee withdrawal	3	5	15	Establish the document of processing guide
Inconsistency between computer key-in records and actual document	2	6	12	Check the difference and build mistake-proofing key-in system

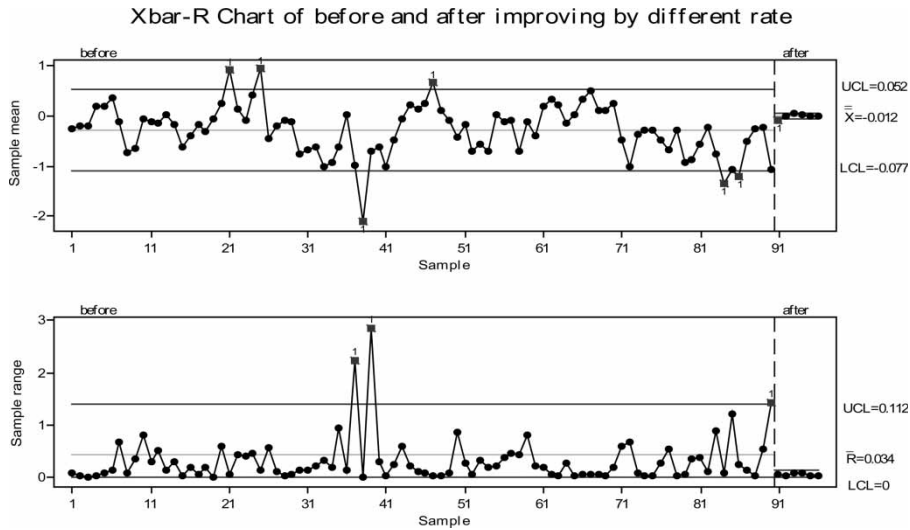


Figure 7. The trend chart before and after the implementation of the LSS project.

influence to determine the final risk score, which is obtained by multiplying influence. The representative example is given in Table 3.

After the adaptation of the LSS approach, the average differentiation rate of forecasting manufacturing costs was reduced from -29.8% in 2006 to -0.0125% in 2007. According to the company's data in 2007, the revenue was around US\$64,280,000 and the manufacturing cost was 24.6% of the revenue, around US\$15,812,880. Here, the cost saving from the LSS improvement can be determined by (sales revenue) * (manufacturing cost rate) * (reduced differentiation rate). Therefore, we can obtain the cost-saving effect in 2007, which is $(64,280,000) * (24.6\%) * (-0.0125\% + 29.8\%) = \text{US\$}4,710,262$.

Conclusion

We have demonstrated the improvement effectiveness of utilising the LSS approach with SSM in the supportive activities, reducing differentiated cost rates of forecasting processes in FPD equipment manufacture. Basically, managers at all levels must commit to invest the resources to initiate, promote, actualise, and support the programme. In other words, providing employees with training, resources, knowledge, and authority to solve problems is crucial for the success of the LSS project. In addition, the LSS approach should focus on understanding the human factor, that is, how to build the right company culture – a culture where people's basic needs are both understood and respected (Dahlgard & Dahlgard-Park, 2006). That is, the company should focus on how to build quality in people by balancing the development of their core competencies with core values.

Due to the LSS project, company-A successfully eliminated wasteful variation, modified business cultures, and created the infrastructure to initiate and sustain greater productivity and profitability. The performance resulted in cost saving of US\$4,710,262 in 2007 and clearly increased the process capability indices of C_p and C_{pk} from 0.78 and 0.64 to 1.62 and 1.49, respectively. The results show that the application of the LSS approach with SSM results in an effective progress in the improvement of supportive activities as well as in the improvement of manufacturing processes.

The limitation of this paper is the use of a single case study. More applications of the LSS approach with SSM should be examined and the results should be generalised. Future studies may include more new tools and techniques in the LSS approach.

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