African Journal of Business Management Vol. 5(31), pp. 12356-12370, 7 December, 2011
Available online at http://www.academicjournals.org/AJBM
DOI: 10.5897/AJBM11.1654
ISSN 1993-8233 ©2011 Academic Journals

Full Length Research Paper

Applying lean six sigma to improve healthcare: An empirical study

Hseng-Long Yeh[1,2], Chin-Sen Lin[3], Chao-Ton Su[4]* and Pa-Chun Wang[5]

[1]Department of Cardiology, Sijhih Cathay General Hospital, Taipei, Taiwan.
[2]School of Public Health, College of Public Health and Nutrition, Taipei Medical University, Taipei, Taiwan.
[3]Department of Industrial Engineering and Management, China University of Science and Technology, Nangang, Taipei, Taiwan.
[4]Department of Industrial Engineering and Engineering Management, National Tsing Hua University, Hsinchu, Taiwan.
[5]Department of Otolaryngology, Cathay General Hospital, Fu Jen Catholic University School of Medicine, Taipei, Taiwan.

Accepted 16 August, 2011

By combining Lean thinking and six sigma (SS), lean six sigma (LSS) is a well-known methodology for providing a powerful process improvement solution. Recently, LSS has become one of the best tools for healthcare system because it develops core competence in healthcare that deal with crucial needs in patient care and safety. This study applies LSS to improve the medical process of acute myocardial infarction. The 'define, measure, analyze, improve, and control steps' of SS find critical-to-quality factors and draw the value stream map to seek out non-value-added activities. The cause and effect diagram is also employed to analyze the root causes of waste and generate the improvement project by brainstorming. Eliminating waste raises the process cycle efficiency. Cycle time of the improved door-to-balloon process decreased by 58.4% and even became less than the ACC/AHA standard (90 min). Process cycle efficiency increased from 32.27 to 51.81%, and the average days of hospital stay decreased by 3 days. Such effects helped save NT$ 4.422 million in medical resource. The study results indicate that LSS not only improved medical quality but also strengthened market competitiveness.

Key words: Lean six sigma (LSS), acute myocardial infarction, door-to-balloon time, process improvement.

INTRODUCTION

Over the last decade, the world has experienced a prompt growth in improvement initiatives, such as lean thinking (lean) and six sigma (SS). There are many well-known cases that have documented the successful implementation of either Lean or SS. Lean and SS promote independent improvements, each with their own unique characteristics. SS views elimination of variation as essential, while Lean attempts to develop a theoretical or practical link between quality and speed (Su et al., 2006). In recent years, Lean Six Sigma (LSS), combining the concept of Lean and SS as an improvement approach, has attracted industrial and academic attention. Although both Lean and SS originate from the manufacturing sector, using both for strategic advantage in the service sector has been widely addressed (George, 2003). Furthermore, LSS has become one of the best tools for healthcare system because it develops core competence in healthcare that deal with crucial needs in patient care and safety.

According to the annual report of the Department of Health of Taiwan (2010), cardiovascular disease is the leading cause of death in the country, and for the past 5 years, over 15,000 people have died of coronary heart disease annually. In particular, the majority of deaths caused by coronary heart disease are those of patients with acute myocardial infarction (AMI). Therefore, the treatment of patients with AMI in an appropriate and

*Corresponding author. E-mail: ctsu@mx.nthu.edu.tw. Tel: 886-3-5742936. Fax: 886-3-5722204.

efficient manner to complete therapy has become a critical issue for healthcare institutions. Patients with acute ST-elevation myocardial infarction (STEMI) should immediately be evaluated for reperfusion of the infarction-related artery (Huang et al., 2006). Treatment of AMI has rapidly evolved over the past five years. One of the core measures for AMI treatment is primary percutaneous coronary intervention (primary PCI) completed within 90 min of arrival for patients experiencing STEMI. This is known as the "door-to-balloon" (D2B) time (Medina et al., 2007). Delayed PCI of patients with STEMI may result in poor hospital survival. Therefore, enhancing early diagnosis and having an efficient and organized process for managing patients may be the most effective strategies for the prevention of high mortality in cases of coronary heart disease.

This study proposes the synergistic combination of Lean and SS for quality and process improvement. It aims to apply the integrated LSS methodology to improve the efficiency of the D2B process. The rationale for combining the two disciplines is also examined and justified on a theoretical basis. An empirical case study of hospital service is conducted to show the deployment processes and to investigate the effectiveness of the methodology proposed. Finally, the conclusions and contributions are presented.

LITERATURE REVIEW

Six sigma

Six sigma has been practiced in the manufacturing sector for many years. More recently, the financial, healthcare, engineering and construction, as well as the research and development sectors have all been improved by SS (Kwak and Anbari, 2006). The healthcare principle of zero tolerance for mistakes and the potential for reducing medical errors are well matched with the SS principles; thus, the techniques and philosophy of SS have fundamentally changed the way healthcare executives view their business.

Chassin (1998) discussed some of the most salient quality problems to improvement in healthcare but encouraged healthcare to learn from industries which are working toward the Six Sigma goal. Commonwealth Health Corporation (CHC) was the first medical institution to implement SS culture, the radiology department executed a pioneering project, and there was a 33% increase in services and a 25% of the unit treatment cost reduced (Thomerson, 2001). The Charleston Area Medical Center focused on supply chain management to test the potential of SS methodologies. Upon reviewing this project, a US$ 1.7 million opportunity was determined in performing the inventory of surgical equipment in storage for over a year (Lazarus and Stamps, 2002). Thus, SS methodology is not only adopted by business enterprises, but also in healthcare industries where its application can enhance a company's competitive advantage in the market.

Lean

The basic Lean concepts are: the relentless elimination of waste through the standardization of processes and the involvement of all employees in process improvement (Dickson et al., 2009). Lean can be described as a set of principles and techniques that drive organizations to continually add value to products or services by enhancing process steps that are necessary, relevant, and valuable while eliminating those that are not. In recent years, Lean has been adopted by various service sectors, such as healthcare institutions. With the continued increase in healthcare costs, many process improvement methodologies have been proposed to address inefficiencies in healthcare delivery; Lean is one such method (Kim et al., 2006). The Virginia Mason Medical Center applied Lean to reduce incidences of ventilator-associated pneumonia from 34 cases with 5 deaths in 2002 to 4 cases with 1 death in 2004, saving the institution over a half-million dollars (Spear, 2005). Intermountain Healthcare also used Lean techniques to reduce the turnaround time of pathologist reports from 5 to 2 days and the time to treatment from 4 h to 12 min (Jimmerson et al., 2005). Dickson et al. (2009) observed that adoption of Lean principles improved the value of care delivered and allowed medical staff to move more patients through the Emergency Department without increasing the length of stay; Lean came to be associated with an increase in patient satisfaction.

Lean six sigma

Since Lean is an approach that seeks to improve flow by eliminating all forms of waste, the process identifies the least wasteful way to provide value to customers. Meanwhile, SS uses a powerful project management framework and statistical tools to identify root cause variation to avoid jumping to solutions. A pragmatic approach can therefore be taken, picking the best bits of each approach. Hence, Lean and SS, both of which provide a systematic method to facilitate incremental process improvement, have been successfully integrated by companies at a strategic and operational level across the whole value stream (Westwood and Silvester, 2007).

In the late 1990s, SS and Lean concepts were adopted locally by Xerox Corp. manufacturing and supply chain operations. In mid-2002, Xerox leaders decided to integrate Lean and SS across the corporation by committing the resources required to enable a robust deployment of the program. Since then, Xerox Lean Six Sigma (LSS) gained increasing momentum (Fornari and Maszle, 2004). In the healthcare industry, DSI laboratories used Lean and SS methodologies to systematically eliminate waste and reduce variation in the clinical laboratory. The net result was savings of more than $ 400,000 in the first year (Sunyog, 2004). In the Netherlands, the Red Cross Hospital adopted the LSS organizational infrastructure, developed organizational competencies, and instituted a process for selecting strategically aligned projects combined with rigorous project management. The net result was a process for institutionalized systematic innovation that consistently delivers the intended end results (Koning et al., 2006). Westwood and Silvester (2007) also described the turnaround time in pathology at the Hereford Hospital to be reduced by 40% in 7 days by improving the flow of specimens through the department and eliminating wasteful activities; the productivity improved by 252% at peak times and the staff was able to finish processing time 15 min earlier than they did previously. Based on these, this study intends to introduce LSS methodology to similarly improve the medical process for AMI.

AMI

AMI is the most serious ischemic heart disease; it causes an interruption of blood supply to a part of the heart, causing heart cells to die. This is most commonly due to the occlusion of a coronary artery following the rupture of a vulnerable atherosclerotic plaque, resulting in ischemia and causes damage or infarction of the myocardium. The typical symptoms of AMI include sudden chest pain with sweating. There is chronobiology of seasonal variation in AMI. Reported cases were decreasing occurrence from winter to fall to spring to summer (Spencer et al., 1998). Statistics from the US state that patients experience AMI every 25 s, with one patient dying from AMI every minute; the American Heart Association (AHA) predicted to spend a budget of over US$ 177.1 billion for AMI treatment in 2010 (AHA, 2010). Based on the type of electrocardiogram for AMI patients, the patients can be divided into two categories: (1) STEMI and (2) non-STEMI. For STEMI patients, primary PCI has become a popular standard treatment of AMI adopted by many medical centers in the world (Libby, 2008). Primary PCI within three hours is mandatory for patients with STEMI. The World Health Organization (WHO) identifies STEMI with at least two of the three conditions: (1) presenting illness of ischemic chest pain; (2) electrocardiogram findings, and (3) cardiac markers. Therefore, the early diagnosis of STEMI and delivery of appropriate treatment are critical issues for cardiovascular patients.

However, delayed primary PCI in patients with STEMI may result in poor hospital survival; the common causes for this include delayed diagnosis, unstable patient condition, and prolonged decision-making time by the family. Studies have shown that longer D2B time is associated with increased in-hospital mortality (McNamara et al., 2006; Medina et al., 2007). Moreover, the American College of Cardiology (ACC) and AHA have also advocated for the rapid transfer of STEMI patients for primary PCI to meet the D2B goal of less than 90 minutes in at least 75% of the patients (AHA, 2007). Therefore, enhancing early diagnosis and having an organized approach for managing patients with AMI may be the most effective strategies to prevent delayed PCI (Huang, et al., 2006).

PROCEDURE FOR IMPLEMENTING LSS METHODOLOGY

The rationale of integrating Lean and SS has been demonstrated, and the next step is to develop an LSS methodology applicable to the type of healthcare service particular to AMI. Given that DMAIC is generally regarded as a virtually unassailable credo in the area of SS process improvement, the discipline was used to develop a LSS methodology. The methodology operates on the DMAIC cycle without losing the well-established groundwork. A conceptual framework of the LSS methodology for improvement is depicted in Figure 1. Extended from the Plan-Do-Check-Act (Pande et al., 2000), DMAIC is the unique operation procedure for LSS. A detailed illustration of the LSS methodology and the statistical tools applied are described in the following sections.

Define/identify value

In this phase, the opportunity for improvement is confirmed, after which, the objective and scope of the project are clearly defined. It is important to determine the VOC to determine the needs of the customers. In fact, VOCs are the basis of CTQ considerations. The supplier-input-process-output-customer (SIPOC) flow chart, the high-level process map of the project, is then developed. The scope of measurement and analysis for the project is determined, and the major items accomplished in this phase are enumerated.

Project charter

This is a document providing a guideline of the problem and a format, which differs according to the industry. The primary deliverables in the establishment of a project charter include business case, project goals and objectives, milestones, project scope, constraints and assumptions, team members, roles and responsibilities, and the preliminary project plan.

Determination of customer needs

External and internal customers are fully identified; this process includes collection and analysis of customer requirements. The administrative department of the government supervises the operation of healthcare institutions in Taiwan, and a regulative institution from the government is also recognized as an external customer.

High-level process map

The SIPOC flow chart is developed to identify cross-functional activities and realize the whole process in a macro-view to determine the output of the process.

Measure/value stream mapping

In this phase, the measurable indicators are identified according to

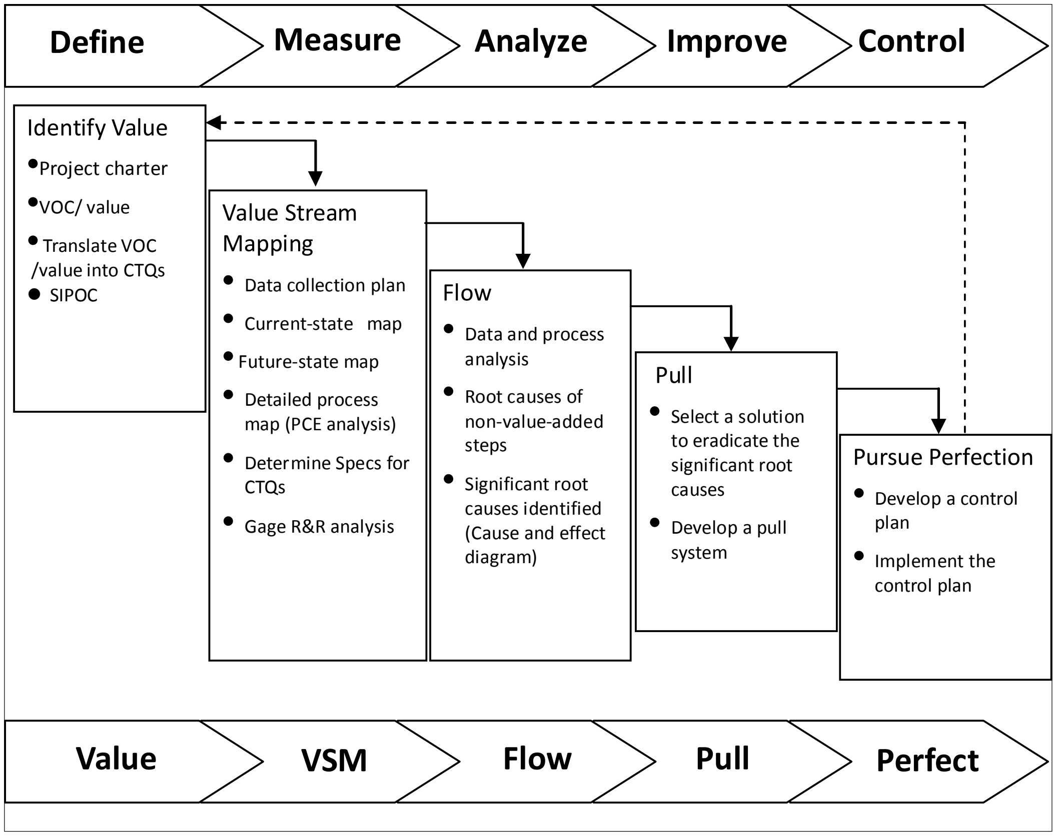

Figure 1. A conceptual framework of the LSS methodology.

the operation definition of CTQ. The internal processes affecting the problem are examined, and performance is also measured. The major steps are described thus.

Measurement system verification

Prior to data collection, the measurement system is verified to confirm the reliability of the data collected. Gauge R and R was used in this study to validate the measurement system.

Data-collection plan creation

The data-collection plan includes issues, such as measurement items, data types, sampling frequency, and format of the data-collection form. A specific time frame is beneficial to creating a consensus of the members of the project.

Construction of a current-state value stream map (VSM)

A current-state VSM shows current work. This is vital for understanding non-value-added steps in the process and for use as the blueprint for improvement. The software eVSM developed by GumshoeKI (2006) was used to construct the VSM in this study.

Process performance measurement

In addition to the indicators used in quality management, including yield, quality cost, process capability, or indicators used in health-care service such as mortality and length of stay (LOS), it is necessary to apply all appropriate indicators for practical concerns. This study discusses the efficiency improvement of the process. Thus, process cycle efficiency (PCE) developed by George (2003) was applied to measure process performance. The PCE is calculated by the following equation:

$$\text{process cycle efficiency (PCE)} = \frac{\text{value - added time}}{\text{total lead time}} \quad (1)$$

Analyze/determine root causes in the flow

In this phase, the data collected is analyzed and the appropriate statistical tools are applied to conduct value stream analysis for identification and validation of root causes for defects that occur in the non-value-added steps. The steps for analysis are enumerated thus.

Data analysis

Statistical analysis is conducted on the data collected from the measure phase; variation of the process is further discussed.

Process analysis

The critical process is analyzed to discover problems in the process and to determine with-value or non-value-added steps for customers. Process value can be classified into three categories: (1) customer value-added (CVA), which is an activity with value for customers; (2) business value-added (BVA), which is a necessary activity from the business viewpoint, but has no true value for customers; and (3) non-value-added (NVA), which is an activity without value from the customer viewpoint (George, 2003).

PCE analysis

Taken from the VSM developed in the measure phase, PCE is an indicator applied to determine the level of waste in the process. In the analyze phase, PCE destruction (PCED) is applied to describe the level of impact of a specific step to the process, it can be calculated with the following equation:

$$\mathrm{PCED} = \frac{\dfrac{(\text{All the PCE except goal value}) - (\text{All PCE})}{\text{All PCE}}}{\text{Demand}} \times 100 \quad (2)$$

A higher value of PCED refers to higher process efficiency consumed by a specific step; this gives the first priority for improvement.

Root cause analysis

Statistical tools, such as the Pareto diagram and the cause and effect diagram as well as brainstorming, are applied to identify the significant root causes of process defects that are prioritized for removal from the process.

Improve/pull

This phase proposes the elimination of the root causes of defects that have the most impact on CTQs in the process. The value-creating steps must occur in a tight sequence, and non-value-added steps must be eliminated to dramatically reduce process flow time. These pull customer demand for products or services. The solutions can be applied to construct a future-state VSM.

Control/pursue perfection

The purpose of this phase is to ensure that solutions endure. The phase is needed to keep track of process performance after improvement and to control the critical variables relating to performance.

AN EMPIRICAL STUDY FOR IMPLEMENTING LSS AT A HOSPITAL

The specific case studied in this research is a practical project for improving the efficiency of D2B time at a private hospital X (name is assumed). The hospital is a 778-bed, private business group-owned, teaching hospital center located in Taipei City, Taiwan.

To improve the service quality for patients and hospital process efficiency, hospital X began to apply SS in 2007. Prior to SS implementation, the management of this hospital also deployed a number of teams to work on specific quality improvement projects and the management believed these pre-SS projects were effective.

In recent years, AMI mortality has been increasing in Taiwan; in 2008 alone, 5,263 patients died from this disease. The ACC/AHA guidelines recommend primary PCI as a preferred reperfusion strategy for patients presenting with STEMI given that revascularization is achieved in a timely manner. The STEMI protocol allows rapid transfer of STEMI patients for PCI to meet the ACC D2B goal of less than 90 min in at least 75% of the patients. To improve medical service quality as well as to reduce mortality and medical cost, the management of hospital X decided to apply LSS to reduce D2B time to improve the efficiency of the STEMI process. The D2B process is examined and the DMAIC procedures are deployed as follows.

Define phase

Project charter

Hospital X needed to improve its medical service quality and practice medical cost saving in order to enhance its competitiveness within the healthcare industry. Facing this situation, improving D2B time for STEMI patients has become a challenge for medical services of X. For project charter, the form of the table is defined, and the project title, champion, project scope, along with other components, has to be well described. The project charter for this case study is shown in Table 1.

Customers' requirement

After several meetings with the directors of hospital X, the problems of the project were discovered. It was found that VOCs came from external customers of the process. The external customers are the patients who are directly affected by the business benefits of the hospital. There is currently a lack of medical information available to cardiac disease patients and no requirements for a hospital to inform the patients.

With this in mind, the governmental institution regulating healthcare must play the important role of supervising hospitals and guiding them to comply with laws and requirements that will benefit the patients. Therefore, governmental institutions are recognized as external customers in this project.

Delay in diagnosis and waiting time for operation was also identified as causes for waste in personnel and resources in Emergency and Cardiovascular Departments. The CTQ of this project are defined as three items: (1) the time for completing electrocardiogram for diagnosing STEMI patients, (2) the waiting time before operation, and (3) the time for conducting balloon inflation.

Table 1. The project charter.

Project number	1723			
Project title	Improve D2B time			
Department	Cardiology, Emergency			
Champion	Huang MD			
Project leader	Yeh MD			
Team member	Title	Tel.	Location	e-mail
Lo MD	Director	91455	Medical Bd. 1F	aa@xxx.org.tw
Huang MD	Supervisor	91359	Medical Bd.2F	bb@xxx.org.tw
Miss Cheng	Staff	92163	Group Bd. B1F	cc@xxx.org.tw
Stakeholders				
Mr. Haung	Technician	91301	Medical Bd.B1F	dd@xxx.org.tw
Mr. Chou	MD	91218	Medical Bd.1F	ee@xxx.org.tw
Miss Yu	Nurse	91282	Medical Bd.1F	ff@xxx.org.tw
Business status	From reducing the D2B time to enhance the competitiveness of the hospital, and to improve the satisfaction of the customers.			
Problem statement	Currently, the average of D2B time is 145 minutes, and which is longer than the ACC/AHA standard.			
Project scope	From the patient arrived the Emergency Department to balloon inflation over infarct related artery			
Project goal	Achieve the goal of reducing D2B time to be less than 90 min for over 75% of the patients.			
Benefit expected	Reduce the LOS of patients and mortality of patients, and so as to reduce 25% of medical cost.			
Project resource	Cooperation of the various Department of Emergency, Cardiology, Nursing, and Medical Technique in human resource and training.			
Starting Date: 2009/01/01		Signature (Champion):		
Completion Date: 2010/03/31		Date:		
Number:		Signature (Sponsor):		
Date:		Date:		

High level flow chart (SIPOC)

From the SIPOC chart, input and output of the process, as well as scope of the project, were identified. The SIPOC of the project is shown in Table 2.

Measure phase

Reducing D2B time for STEMI patients is the objective of this project. The operating definition of D2B time is described as follows: a patient arrives in the Emergency Room and undergoes confirmation of classification by a nurse; after registration, the time record starts. The STEMI patient is diagnosed and confirmed by a physician of the Emergency Department who starts to contact the on-duty Cardiologist to confirm the diagnosis; the nurses of the Emergency Department prepare for operation and transfer the patient to a catheterization laboratory for operation. The time record ends at the completion of balloon inflation. Using the CTQs measured in the Define phase, D2B time can be defined by various sub-processes listed thus:

D2B time (y_1) = the time at which the patient arrives in the Emergency Room until the electrocardiogram, which confirms STEMI (y_1) + the waiting time before the emergency operation (y_2) + the time for balloon inflation (y_3).

Table 2. High level flow chart (SIPOC).

Supplier	Input	Process	Output	Customer
Emergency room (ER)	ER Nurse ER physician	Triage inspection classification Initial diagnosis	Anamnesis, Inspection sheet Medical chart and order	Patient
	Medical order	Take electrocardiogram	Electrocardiogram report	Nurse, patient
	ER physician	Diagnosis	Major diagnosis confirm, deliver prescription	Patient
ER physician Pharmacy	Prescription MEDICINE	Deliver medicine	Taking medicine	Patient
Emergency room	ER physician	Contact cardiologist	Complete contacting	Cardiac physician
Cardiovascular department Emergency room	Cardiologist ER nurse	Cardiologist illustration Operation preparation	Complete illustration and inform consent Setting down pre-operation preparation	Patient, Families
Emergency room	ER nurse	Transfer to catheterization laboratory	Arrive at catheterization laboratory	Patient
Cardiovascular department	Technician Cardiologist	Pre-operation preparation Diagnosis of coronary	Start surgery Confirm coronary infarct related artery	Patient
	Cardiologist	Explanation	Appropriate communication	Patient family
	Cardiologist	Balloon inflation	Myocardial reperfusion	Patient

The expecting goals of these sub-processes are: (1) less than 20 min for (y_1) ,(2) less than 50 min for(y_2), and (3) less than 20 min for(y_3) ; reducing (y_1), (y_2), and (y_3) can improve the D2B process.

Prior to measurement, the repeatability and reproducibility of the system was validated. Prior to on-site measurement, pictures of the trained operators in the five sub-processes were taken (k); two of the operators (i) were recorded as they took two measurements (j), respectively. Consequently, measurement system capability was evaluated by statistics (mean). The collected data are summarized in Table 3.

The reports of Minitab analysis of Gage R and R give percentage $RR_{total\ variation}$= 3.43% and number of distinct categories = 41%; the values are less than 10 and larger than 5%, respectively. Such promising results imply that the measurement system is acceptable. On-site data were collected once the measurement system was validated. In this work, a D2B time less than 12 h was collected from January to September 2009 from a total of 40 cases. Data were analyzed with a statistical normality test, and the result demonstrates that the data are not normalized. Hence, the Box-Cox transformation was used to transfer data. The optimum data of λ in Box-Cox transformation was -1 and the normal probability diagram was analyzed and identified to comply with the assumption for normalized data.

The I-MR control chart was then plotted using the transformed data in Figure 2; here, one outliner needed to be deleted. Three response variables were tested in the same procedure resulting in three outliners that needed to be deleted. Consequently, process capability was analyzed. For the specification, D2B time (y) should be less than 90 minutes, the capability indicator (C_{pk}) of the process was -0.25, and the capability indicators (C_{pk}) (y_1), (y_2), and (y_3), were 0.03, -0.24 and -0.31, respectively. Note that all of these were all less than 1.5. The analysis demonstrated a large space for process improvement.

To measure the process performance, the sub-processes were diagramed into VSMs. The value stream map for (y_1) is shown in Figure 3. In addition, PCE proposed by George (2003) were calculated to analyze process compliance to Lean. The PCE of the sub-processes for (y_1), (y_3) and (y_3) are: 21.03, 24.46 and 64.19%, respectively.

Analyze phase

In terms of the data defined as response variables and expecting goal values, we proceed to analyze the

Table 3. The analyzed data of Gage R and R.

X_{ijk}		k = 1	2	3	4	5	Average value
i = A	j = 1	189	17	62	120	157	
	j =2	190	17	62	120	156	
Average $\overline{X}_{A\bullet k} =$		189.5	17	62	120	156.5	$\overline{X}_{A\bullet\bullet} = 109$
Average $R_{Ak} =$		1	0	0	0	1	$\overline{R}_{A\bullet} = 0.4$
i = B	j = 1	184	16	57	118	153	
	j =2	184	17	57	118	153	
Average $\overline{X}_{B\bullet k} =$		184	16.5	57	118	153	$\overline{X}_{B\bullet\bullet} = 105.7$
Average $R_{Bk} =$		0	1	0	0	0	$\overline{R}_{B\bullet} = 0.2$
Average $\overline{X}_{\bullet\bullet k} =$		186.75	16.75	59.5	119	154.75	

$\overline{X}_{\bullet\bullet\bullet} = 107.35$ $\quad$ $R_{\bullet\bullet} = 0.3$

$R_{part} = \text{Max}\ (\overline{X}_{\bullet\bullet k}) - \text{Min}\ (\overline{X}_{\bullet\bullet k}) = 170$ $\quad$ $R_{operator} = \text{Max}\ (\overline{X}_{i\bullet\bullet}) - \text{Min}\ (\overline{X}_{i\bullet\bullet}) = 3.3$

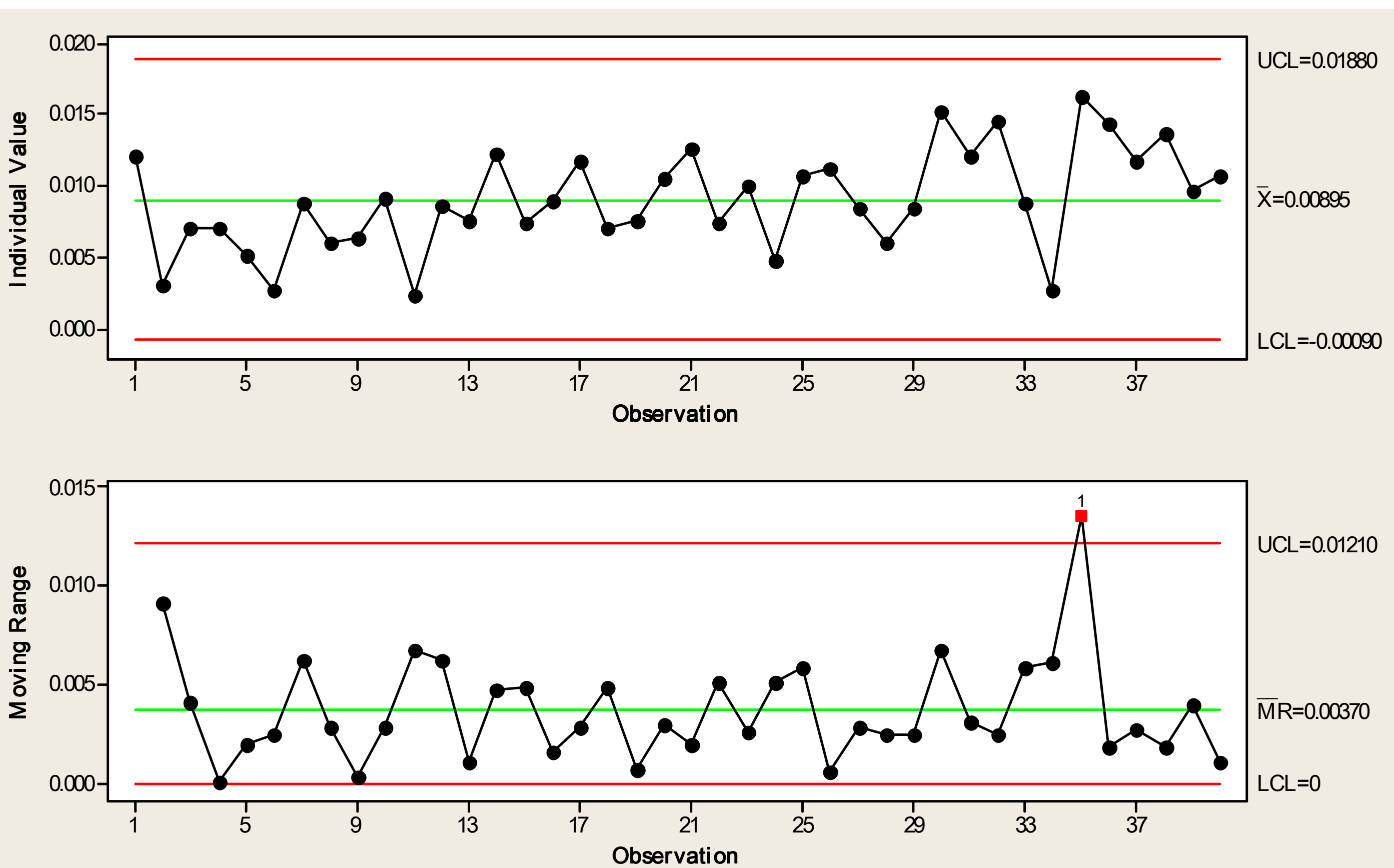

Figure 2. I-MR chart of box-cox transformation for D2B time.

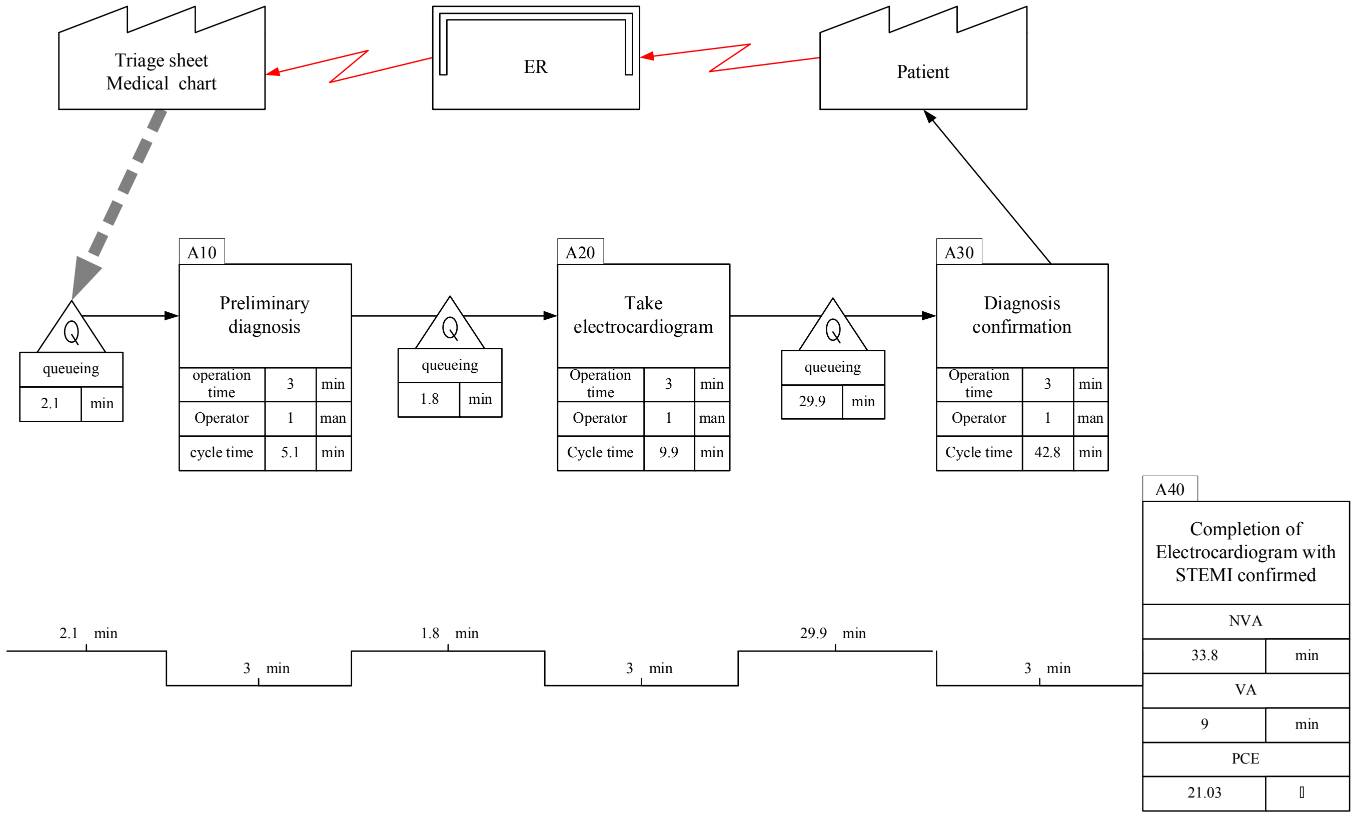

Figure 3. The value stream map for y_1.

Table 4. The conformed percentage of the goal value.

Response variable	Average	Standard deviation	Goal value (min)	Conformed percentage of goal value
D2B Time(y)	139.2	85.1	≤90	28
the time patient arrives the Emergency Room to completion of Electrocardiogram with STEMI confirmed (y)	42.8	77.6	≤20	64
the time to wait for emergency operation (y_2)	65.4	21.3	≤50	19
the time for balloon inflation (y_3)	31.0	18.6	≤20	25

sampling data, and there were 36 effective samples and the average value of D2B time was 139.2 min, and the standard deviation was 85.1 min, it was 28% conformed with the goal value. The conformed percentage with goal values for the various response variables were summarized as Table 4, and which showed the variance of the process was large, that means, the D2B time process was needed to be improved.

Each specific step of the D2B time process was analyzed for added value. They were verified with three categories: CVA, BVA, or NVA (Table 5). Many of the steps related to waiting on queues were found to be NVA.

PCED for each step was calculated and applied to determine the value for each step as well as its priority for improvement. PCED values of the steps 'Diagnosis confirmed' (y), 'Preparation before surgery' and 'Transfer to catheterization laboratory' (y_2) and 'Balloon inflation surgery' (y_3) were larger than zero, indicating that these steps must be prioritized for improvement to significantly enhance process efficiency. From the analysis result of PCED, there are 5 steps to be improved in this stage: 'Diagnosis confirmed', 'Give medicine', 'Preparation before operation', 'Transfer patient to catheterization laboratory', and 'Balloon inflation operation'. The cause

Table 5. The process value analysis.

Process item	Step	VA/BVA/NVA	Time (min)	Description
Queue in line	Wait for diagnosis of ER physician	NVA	2.1	According to the result of inspection classification, wait for diagnosis of ER physician
Preliminary diagnosis	Preliminary Diagnosis from ER physician	VA	3.0	In terms of the ER physician diagnosis, if there is suspected to be STEMI with chest pain, order of electrocardiogram is delivered
Queue in line	Wait for Taking Electrocardiogram	NVA	1.8	Wait for nurse to take electrocardiogram
Take Electrocardiogram	Take Electrocardiogram	VA	3.0	If there is chest pain and suspected to be STEMI, the electrocardiogram is mandatory for ER physician diagnosis
Queue in line	Wait for report of Electrocardiogram and ER physician	NVA	29.9	Wait for the electrocardiogram is made, queue in line for Emergency physician diagnosis
Diagnosis	Diagnosis of ER physician and treatment sheet	VA	3.0	According to the result of electrocardiogram, if the STEMI is confirmed, ER physician delivers the treatment sheet for patient to get the medicine
Queue in line	Wait for getting the medicine and wait for nurse to assist patient taking medicine	NVA	8.9	The family of the patient goes to get the medicine, and back to ER to give the medicine to nurse
Get medicine	Get medicine	VA	1.0	From the assist of ER nurse to help patient taking the medicine
Queue in line	Wait for ER physician contacting cardiac MD	NVA	7.9	Wait for ER physician helping to contact with the cardiac MD
Contact cardiac MD	Contact Cardiologist	VA	1.0	ER MD contacts with the Cardiologist and confirm diagnoses
Queue in line	Wait for Cardiologist	NVA	10.4	Wait for Cardiologist and confirm diagnoses
Explanation	Cardiologist explains the condition of patient	VA	7.0	Cardiologist explains the condition of the patient to patient's family and gets inform of consent
Queue in line	Wait for ER nurse to prepare the operation	NVA	19.1	Wait for ER nurse to prepare the operation
Preparation before operation	ER preparation before operation	VA	0.0	ER nurse help patient to change the clothes, and set intravenous line
Queue in line	Wait for preparation of catheterization laboratory Wait for ER nurse to transfer	NVA	21.4	Wait for the preparation of catheterization laboratory, and wait for ER nurse to transfer the patient

Table 5. Contd.

Transfer the patient	ER nurse transfer the patient to catheterization laboratory	VA	5.0	ER nurse assists to transfer the patient to catheterization laboratory
Queue in line	Wait for move on the catheterization laboratory table	NVA	0.5	Wait for technician assisting to move patient to catheterization laboratory table
To catheterization laboratory table	Patient is moved to catheterization laboratory table	VA	2.0	Move patient to catheterization laboratory table
Operation preparation	Medical stuff prepare operation	BVA	3.3	Before operation, setting vital signs monitor, sterilization, and cover sterilized sheet by medical stuff.
Diagnosis of coronary artery	Diagnosis of coronary artery	VA	7.9	Diagnosis of coronary artery, and confirm the infracted related artery and culprit lesion.
Condition explanation within the operation	Condition explanation within the operation	NVA	7.3	Explain the condition of the patient to the patient's family
Balloon inflation	Conduct the balloon inflation operation	VA	10.0	Proceed the balloon inflation operation through the percutaneous transluminal coronary angioplasty (PTCA)

and effect diagram was used to analyze root causes of waste in these steps (Figure 4).

From the cause and effect diagram analysis in Figure 4, relevant medical personnel were invited to evaluate the potential impacts of each waste root cause prioritized for improvement. The evaluation results are shown in Table 6. Considering the limited time and resource, the first three priorities were listed as items for improvement.

Improve phase

Brainstorming was conducted to discuss the countermeasures for each item for improvement:

1. Not fully functional triage: revise SOP (standard operation process); during patient inspection patient, if the patient arrived with chest pain, send the patient to take the electrocardiogram test before physician diagnosis to avoid valueless waiting in queue.
2. It is a waste of time for the treatment sheet to be hand written by the physician: add an AMI module function for the medical order command in the information system; after major diagnosis is confirmed, the command can be directly selected and the computer delivers the relevant treatment sheet automatically.
3. Shortage of ER nurses: propose the addition of nurses focused on providing service to AMI patients to the management of hospital X.
4. Waste of time in getting the medicine: the medicine (called a STEMI medication easy pack) must be easily available in the emergency department, and the family of the patients need not go to the pharmacy and wait in queue for the medicine.
5. Lengthy on-duty cardiologist transportation time: there used to be 17 cardiologists on-duty, but this has now been reduced to the three who live within five minutes from the hospital.
6. Lengthy duration in obtaining an informed consent: an easy to understand AMI description for the patient and the family described by intuitive pictures makes the condition easier to explain.
7. The procedure to prepare the operation-related forms is tedious: collect all operation-related sheets in a specific folder to reduce the time of looking for various sheets.
8. The catheterization laboratory staff cannot arrive on time: this is caused by a delay in contacting the staff. Contact catheterization staff upon diagnosis confirmation by the emergency physician. Emergent duty-recall procedure must be initialized immediately by the emergency physician.
9. The necessary equipment have diverse varieties and delivery wastes time: setting up all STEMI operation equipment in one box (called the STEMI catheterization

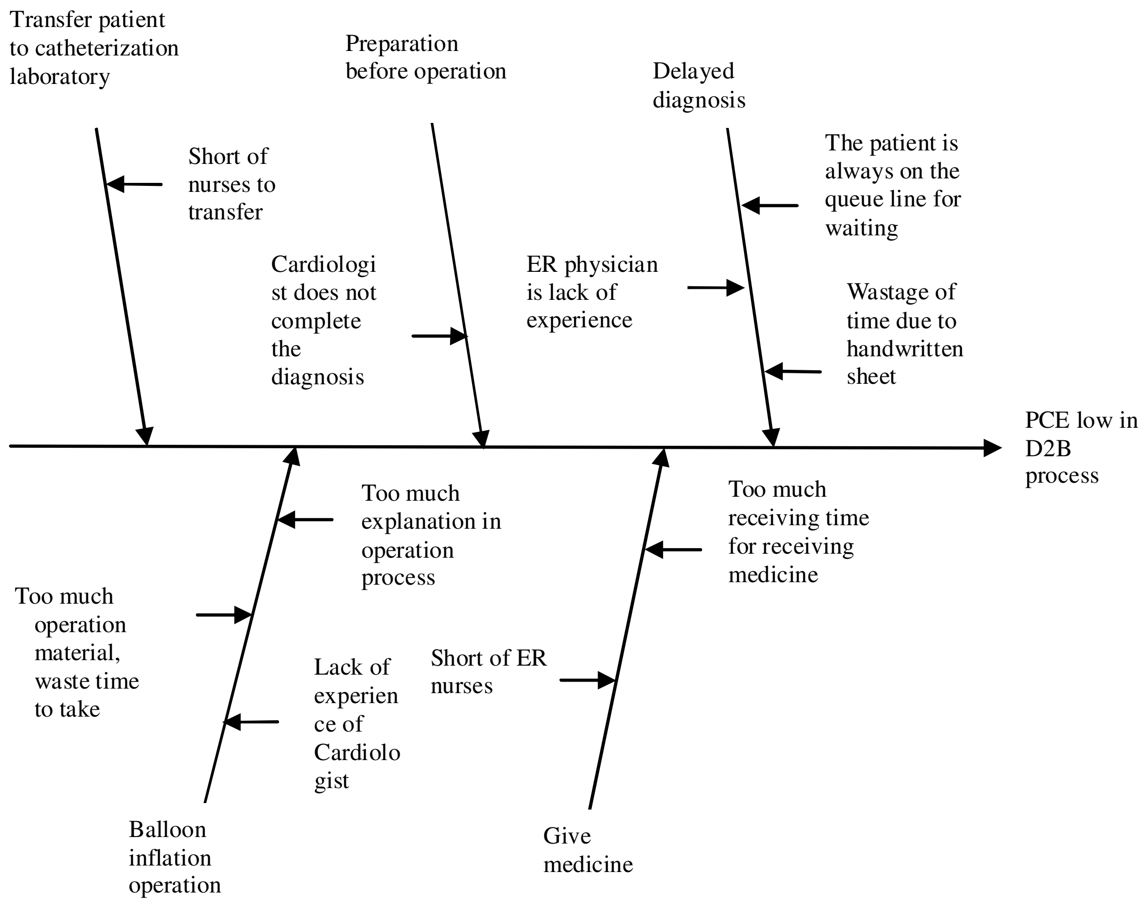

Figure 4. The cause and effect diagram for D2B process.

Table 6. The evaluation result of D2B root causes.

The cause to make waste		Effort	Impact	Priority
The patient is always in queue line	Only one ERG	High	Low	6
	Treatment station not full functioned	Low	High	1
ER physician lack of experience		Medium	Medium	4
Treatment sheet is hand written by physician, waste time		Low	Medium	2
ER nurses shortage		Medium	High	3
Waste time in receiving medicine		Low	High	1
Cardiologist does not confirm diagnosis	Can not contact with the on-duty Cardiologist	High	High	5
	Long on-duty Cardiologist transportation time	Low	High	1
	Long duration to get inform consent	Low	High	1
It is tedious to prepare the operation related sheets	To place the sheet in dispersion	Low	Medium	2
	Diverse varieties of sheets for waste time to look for	Low	Medium	2
The corridor is too crowded		High	Low	6
The personnel of catheterization laboratory do not arrive		Low	High	1
No exclusive elevator		High	Low	6
The equipment is with diverse varieties, and waste time to deliver		High	Low	2
The explanation within the operation waste time and no necessary		Low	Medium	2

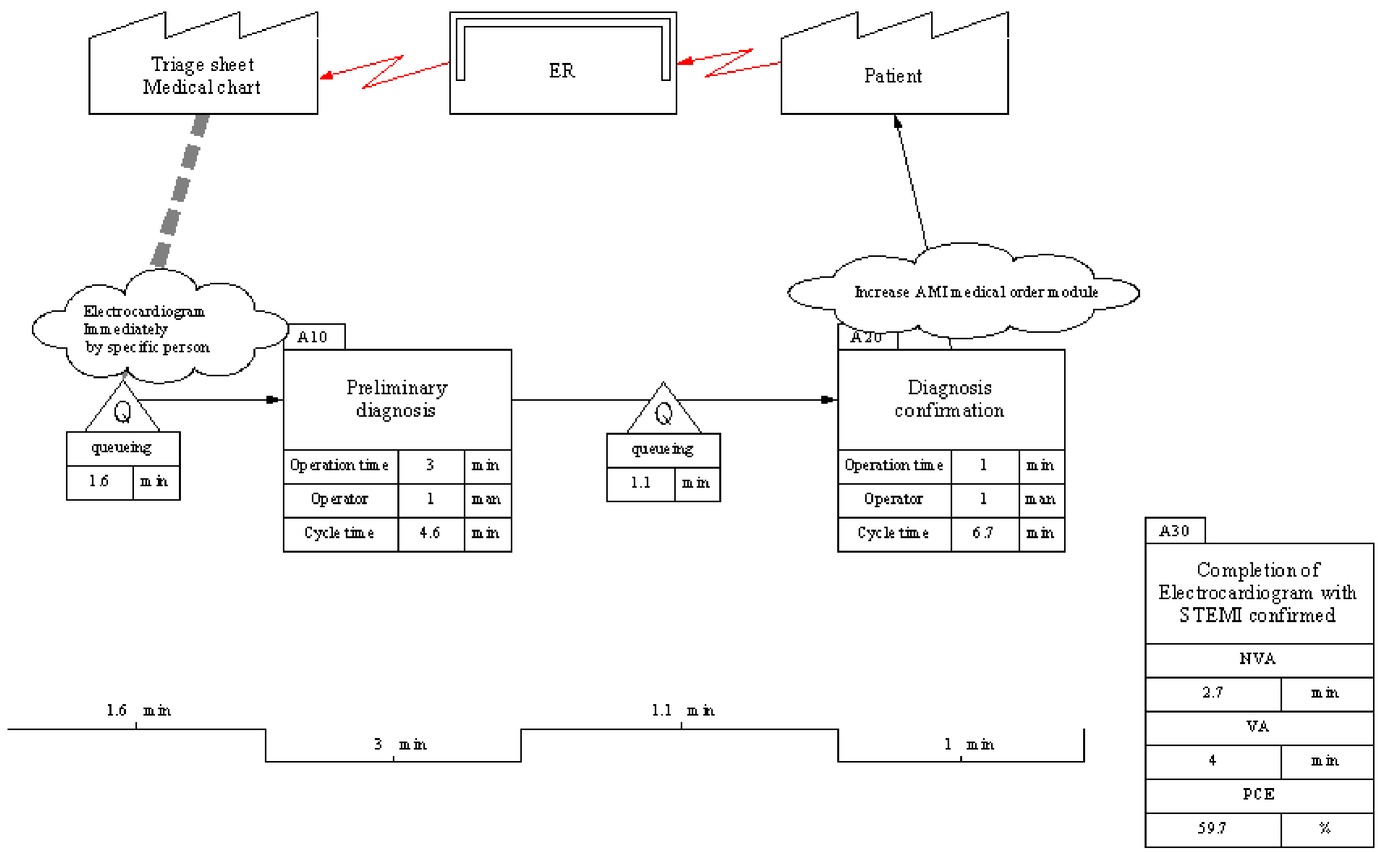

Figure 5. The Future-state value stream map for y_1.

easy box) to reduce preparation time. This may be prepared without any assistance.
10. Explanation within operation wastes time and is not necessary: exempt explanation within the operation.

After the countermeasures were approved and announced by the executives of hospital X, data after improvement application were collected from November 2009 to March 2010, for which a total of 10 cases were collected. The data before and after improvement were compared; and from the analysis, the total time was reduced from 139.2 to 57.9 min, showing a 58.4% of improvement in the D2B process. The plotted future-state VSM for y_1 is shown in Figure 5.

Control phase

The D2B process was reviewed after countermeasure implementation. The D2B time reduced by as much as 58.4%, was even less than the ACC/AHA standard (90 minutes), and also achieved the goal value of the project. The manufacturing capability indicator (C_{pk}) of y_1, was greater than 1.33, indicating a qualified capability, but the C_{pk} of y_2 and y_3 were still less than 1.33 demonstrating that the process can still be improved. The process cycle efficiency of y was greater than 50%, showing that the service level reached certain quality standards; the others also showed values far better than the previous ones.

To maintain the quality level after the process improvement as well as to prevent further errors, the control policies for each countermeasure were proposed (Table 7). Through these control policies, the variations for each process are expected to be reduced. In addition, emergency plans for the CTQs also constructed to cope with incidents and to continue process improvement. The emergency plan is shown in Table 8.

Process efficiency analysis

To verify the benefits of the project, the relevant costs before and after the project were collected and analyzed. The all cause disease-specific mortality rate of STEMI was 5.56% (2/36) before the project. There was no mortality case until the end of measurement (0/10). The non-value-added time reduced by 70.7%, improving process efficiency and providing better service for patients. Given that the cost of personnel and material increased, LOS of patients was reduced for 3 days, and the unit consuming cost for one patient was NT$ 67,000 for an average of 5.5 AMI patients per month. The annual

Table 7. Control policy of the process.

Measure of improvement	Responsible department	Control
For patient inspection, the patient with chest pain is taken with Electrocardiogram directly by specific person	Emergency department	Revise SOP and implement
Create AMI medical order module	Information department	Meet with unusual situation, notify the information department to eliminate the error
Put the operation relevant documents into the special folder	Emergency department	Prepare 20 special folders, and review the inventory on the end of the month and replenish the number of folders used
Three Cardiologists on duty who lives within five minutes transportation time.	Cardiovascular department	Arrange the on-duty Cardiologist monthly and notice to Emergency department
Emergent duty-recall procedure was initialized immediately by emergency physician after confirmed diagnosis.	Emergency department	Record the time for duration of emergent duty-recall procedure
STEMI medication easy pack at emergency room	Emergency department	Prepared two sets of STEMI medication easy pack, replenish immediately after used. The integrity and quality of pack was verified by in charge of nurse daily.
STEMI catheterization easy box	Cardiovascular department	Prepared two sets of STEMI catheterization easy box, replenish immediately after used. The integrity and quality of box was verified by director of catheterization room daily.

Table 8. The emergency of the process.

Variable	Goal	Emergency plan
The time patient arrives the Emergency Room to completion of Electrocardiogram with STEMI confirmed (y_1)	≤20 min	When the time exceeds the goal, the unusual report should be proposed and review monthly
The time to wait for emergency operation (y_2)	≤50 min	
The time for balloon inflation (y_3)	≤20 min	
Value stream map analysis	none	The map has to be plot every six months for reviewing the process information, if necessary, the process should be re-designed
Average LOS	Smaller is better	Review performance every season, and connect with the target of the hospital evaluation, and hold the review meeting regularly
Medical expense		
Mortality in hospital		

cost saved per year reached NT$ 4.422 million.

Conclusions

Medical errors or variation in healthcare services are highly discussed topics in the healthcare industry; hence, various improvements on medical and service quality have been proposed by management entities within the industry. This study has focused on the improvement of the D2B process by applying LSS methodology to reduce D2B time by 58.4% and achieve an annual operation cost saving of NT$ 4.422 million. The study has successfully demonstrated a brilliant model for the healthcare industry and has created a novel model for improving service delivered to AMI patients. The contributions of this study are described as follows:

1. Integrating the Lean concept and the SS structure in the healthcare industry;
2. Developing an appropriate structure of LSS geared toward the healthcare industry;
3. Discussing STEMI medical service processes and the meaning of process indicators;
4. Discovering root causes of process cycle efficiency reduction from the case study;
5. Creating a service process, which reduced D2B time; and
6. Upgrading medical quality and improving business operation performance.

Through these contributions, the medical quality of hospital X was improved and the market competitiveness of the hospital was strengthened. Besides, in this study, the causes of delayed D2B time were collected mainly basing on the sub-processes made by the time delayed, however, the causes of delayed D2B time might be induced by other man-made reasons. The various causes of delayed D2B time can be recorded and analyzed in further discussion, and the time for D2B process will be more effective and improved.

REFERENCES

American Heart Association (AHA) (2007). Focused Update of the ACC/AHA 2004 Guidelines for the Management of Patients With ST-Elevation Myocardial Infarction. from http://www.americanheart.org/presenter.jhtml?identifier=3053626

American Heart Association (2010). Heart Disease and Stroke Statistics from http://www.americanheart.org/presenter.jhtml?identifier=1200026

Chassin MR (1998). Is Health Care Ready for Six Sigma Quality? Milbank Q., 76(4).

Department of Health, Taiwan (2010/08/30). 2010 Cause of Death Statistics. http://www.doh.gov.tw/EN2006/index_EN.aspx

Dickson EW, Singh S, Cheung DS, Wyatt CC, Nugent AS (2009). Application of Lean Manufacturing Techniques in the Emergency Department. J. Emerg. Med. 37(2):177-182.

Fornari A, Maszle G (2004). Lean Six Sigma leads Xerox. Six Sigma Forum Magaz., 11-16.

George ML (2003). Lean Six Sigma for service: how to use lean speed and six Sigma quality to improve services and transactions. New York, McGraw-Hill.

Huang SH, Kung CT, Chew G, Han TC, Lee WH (2006). Delayed primary Percutaneous coronary intervention for acute myocardial infarction in the emergency department. J. Emerg. Med, 8(2): 49-53.

Jimmerson C, Weber D, Sobek DK (2005). Reducing waste and errors: piloting lean principles at intermountain healthcare. Joint Commission J. Qual. Patient Safety, 31(3): 249-257.

Kim CS, Spahlinger DA, Kin JM, Billi JE (2006). Lean health care: what can hospitals learn from a world-class automaker? J. Hosp. Med., 1(3): 191-199.

Koning H, Verver J, Heuvel J, Bisgaard S, Does R (2006). Lean six sigma in healthcare. J. Heal. Care Qual., 28(2): 4-11.

Kwak YH, Anbari FT (2006). Benefits, obstacles, and future of six sigma approach. Technovation. 26(5-6): 708-715.

Lazarus IR, Stamps B (2002). The promise of Six Sigma. Manage. Healthc. Exec., 12(1): 27-30.

Libby P (2008). Braunwald's Heart Disease: A Textbook of Cardiovascular Medicine (8th ed.). Philadelphia: Saunders/Elsevier.

McNamara RL, Wang Y, Herrin J, Curtis JP, Bradley EH, Magid DJ, Peterson ED, Blaney M, Frederick PD, Krumholz HM (2006). Effect of door-to-balloon time on mortality in patients with ST-segment elevation myocardial infarction. J. Am. Coll. Cardiol., 47(11): 2180-2186.

Medina L, Sumter D, George J, Rushenberg J, Leonard C (2007). Reducing door-to-balloon times in acute myocardial infarction. J. Emerg. Nurs., 33(4): 336-341.

Pande PS, Neuman RP, Cavangh RR (2000). The six sigma way: how GE, Motorola, and other top companies are honing their profession. New York: McGraw-Hill.

Spear SJ (2005). Fixing health care from the inside, today. Harv. Bus. Rev., 83(9): 78-91.

Spencer FA, Goldberg RJ, Becker RC, Gore JM (1998). Seasonal distribution of acute myocardial infarction in the second national registry of myocardial infarction. J. Am. Coll. Cardiol., 31: 1226-1233.

Su CT, Chiang TL, Chang CM (2006). Improving service quality by capitalizing on an integrated lean six sigma methodology. Int. J. Six Sigma Competitive Advantage, 2(1):1-22.

Sunyog M (2004). Lean management and six-sigma yield big gains in hospital's immediate response laboratory. Quality improvement techniques save more than $400,000. Clin. Leadersh. Manage. Rev., 18(5): 255-258.

Thomerson LD (2001). Journey for excellence: Kentucky's commonwealth health corporation adopts six sigma approach. Annual Quality Congress Proceedings. Proceed, 55: 152-158.

Westwood N, Silvester K (2007). Eliminate NHS losses by adding lean and some six sigma. Oper. Manage., 5: 26-30.