DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

SIX SIGMA AND AN IMPLEMENTATION IN AUTOMOTIVE INDUSTRY

by
Mutlu ŞEN

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İZMİR

SIX SIGMA AND AN IMPLEMENTATION IN AUTOMOTIVE INDUSTRY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"SIX SIGMA AND AN IMPLEMENTATION IN AUTOMOTIVE INDUSTRY"** completed by **MUTLU ŞEN** under supervision of **ASST. PROF. DR. BİLGE BİLGEN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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SIX SIGMA AND AN IMPLEMENTATION IN AUTOMOTIVE INDUSTRY

ABSTRACT

Six Sigma is viewed as a systematic, scientific, statistical and smarter approach for management innovation and focuses on establishing world class business performance. The main identifiers and supreme features of Six Sigma amongst other improvement techniques are; its rich ground which covers many customer oriented and problem solving techniques and its scientific methodology which is based on statistics. One of the most important factors of achieving success is selection of the right Six Sigma projects.

One of the most important factors of achieving success is selection of the right Six Sigma projects. This paper presents a case study in which both Six Sigma project is selected and Six Sigma methodology is adopted to reduce the energy cost by optimization of material transferring heat loss in an automotive supplier industry. To cope with ambiguity and vagueness in the Six Sigma project selection problem, the Fuzzy Analytic Hierarchy Process has been used. The paper also describes how various tools and techniques are employed in the different phases within the Six Sigma methodology and how the improvement actions are implemented. Tools like Voice of Customer (VOC), Failure Mode Effect Analysis (FMEA), Critical to Quality tree (CTQ), boxplot and scatterplot analysis, hypothesis tests, Taguchi method are used in the DMAIC (Define, Measure, Analysis, Improve, Control) phases. In conclusion, the key benefits of and experience gained from this project are emphasized.

Keywords: Six Sigma, DMAIC, Project Selection, Fuzzy Analytic Hierarchy Process, Taguchi method, automotive industry

ALTI SİGMA VE OTOMOTİV ENDÜSTRİSİNDE BİR UYGULAMA

ÖZ

Altı Sigma yönetimde yeniliği sağlamak için sistematik, bilimsel, istatistiksel ve akıllı bir yaklaşım olarak görülmekte aynı zamanda dünya sınıfında bir firma olma yolunda odaklanmayı sağlamaktadır. Altı Sigma'yı mevcut diğer tekniklerden ayıran üstün yönleri; kendisinden önceki pek çok müşteri odaklı yöntemleri ve problem çözme tekniklerini içinde barındırması ve istatistik bilimini temel alan bir metodoloji olmasıdır. Altı Sigmada başarıya ulaşmanın en önemli faktörlerinden biri de doğru Altı Sigma projesinin seçimidir.

Başarıya ulaşmadaki en önemli faktörlerden biri doğru Altı Sigma projesinin seçimidir. Bu çalışmada hem Altı Sigma proje seçimi hem de otomotiv endüstrisinde metal transferi sırasındaki ısı kayıplarının optimizasyonu ile enerji maliyetlerinin azaltılmasına yönelik Altı Sigma metodolojisinin adaptasyonu ile ilgili uygulamaya yer verilmiştir. Proje seçimindeki belirsizlik ile başa çıkmak için Bulanık Analitik Hiyerarşi Prosesi kullanılmıştır. Bu çalışma aynı zamanda Altı Sigma metodolojisinin farklı adımlarında çeşitli araç ve tekniklerin nasıl kullanıldığını ve iyileştirme aksiyonlarının nasıl uygulandığını göstermektedir. Müşterinin sesi, Hata Türü ve Etkileri Analizi, Kritik Kalite parametreleri ağacı, kutu grafiği, dağılım grafiği, hipotez testleri, Taguchi metodu gibi araçlar TÖAİK(Tanımlama, Ölçme, Analiz, İyileştirme, Kontrol) adımlarında kullanılmıştır. Sonuç olarak bu projeden elde edilen yararlar ve tecrübeler vurgulanmıştır.

Anahtar sözcükler : Altı Sigma, TÖAİK, Proje Seçimi, Bulanık Analitik Hiyerarşi Prosesi, Taguchi Metodu, Otomotiv endüstrisi

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CHAPTER ONE
INTRODUCTION

In this chapter, the background, motivation and aim of this study are mentioned, and organization of this thesis is outlined.

1.1 Background and Motivation

Under the pressure of the competitive conditions of modern economics, only the firms those ensure the correct way of doing business in its all processes stand in the market. Corporations who can minimize the waste and errors, who owns a management philosophy that can convert mistakes to success by giving life to learnings from the past, will be the ones to survive in the market making profits and keeping an efficient business. It is not very rare to see the impact of a simple mistake or an error to cause a few times of the company's yearly profit.

Six Sigma is an approach that aims to reach a level near perfection and which rises on the idea of improvement and redesign of business processes in order to maintain continuous improvement in job performance and customer satisfaction level.

Harry & Schroeder (2000) describe Six Sigma as a ‘‘business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction’’ (p. 7).

Basic rule of a challenging competition is determining customer requirements correctly and satisfying these requirements faster than opponents, with high quality and economical products. Six Sigma considers everything that conflict with this rule as a problem.

Kumar et al. (2007) point out that Six Sigma is now often thought of as the new mantra in the corporate world. They indicate that manufacturing companies have been successful in leveraging Six Sigma, as a corporate strategy, to reduce the number of defective units from manufacturing processes thereby reducing costs and improving profits over the past few years. Six Sigma philosophy has lots of good impacts on financial results of companies. Anonymous (2003) reports that Six Sigma implementations have resulted in phenomenal returns on investment to the corporate world, more than double the original investment in many cases. What is new in Six Sigma when compared to prior quality management approaches is more its organizational implementation rather than the underlying philosophy or the quality tools/techniques employed (Schroeder et al., 2007).

Companies that run Six Sigma focuses on the problems that cause inefficiency and decreases the sigma level. Some benefits of Six Sigma can be listed as decrease in costs and error ratio, efficiency, increase in market share, customer and employee satisfaction levels and positive effect on company culture. Companies which implement Six Sigma approach decreases the number of error and mistake level in its product and services to a minimum.

The main identifiers and supreme features of Six Sigma amongst other improvement techniques are; its rich ground which covers many customer oriented and problem solving techniques and its scientific methodology which is based on statistics. These main features enable Six Sigma to reach at the actual success which many techniques can only predict in theory.

Companies that implement Six Sigma are not only saving millions of dollars but also are having significant increases in productivity, efficiency, quality and customer satisfaction levels. Although Turkey can be thought of as a starter in Six Sigma concept– which is considered as the ultimate state of Total Quality Management- , there are many companies that realize successful implementations which eventually carried their operations to one step closer to perfection.

1.2 Aim of Thesis

In the relevant literature the studies about Six Sigma generally focus on tools and techniques, methodology, success factors, challenges, benefits and project selection.

As Six Sigma is a project-driven methodology, it is essential to prioritize projects which provide maximum financial benefits to the organization. Generating and prioritizing the critical Six Sigma projects, however, are real challenges in practice (Buyuközkan & Öztürkcan, 2010). Although, selecting of the right Six Sigma project is one of the most sensitive elements in the deployment of Six Sigma, the literature on Six Sigma project evaluation and project selection is rare (Yang & Hsieh, 2009). Most papers have used descriptive research methodologies or empirical methodologies based on case studies or surveys. Six Sigma applications has been studied in detail but without taking Six Sigma project selection into account.

In our study we discuss Six Sigma from project selection to the end of project completion. Fuzzy Analytic Hierarchy Process (FAHP) is used to select most beneficial Six Sigma project. Using fuzzy set theory provides to deal with uncertainty. FAHP takes into account the uncertainty associated with the mapping of one's perception to a number. The most beneficial project was selected as a Six Sigma project among three candidate projects. After selection of the project, a case study that shows Six Sigma methodology (Define, Measure, Analyze, Improve, Control – DMAIC) steps in detail. Tools like Voice of Customer (VOC), Failure Mode Effect Analysis (FMEA), Critical to Quality tree (CTQ), box plot and scatter plot analysis, hypothesis tests are used in the DMAIC phases. Also Taguchi experimental design is used to find optimum solution to a four factors problem. By means of Taguchi method the number of experiment can be reduced and optimal solution can be provided.

1.3 Organization of Thesis

This study consists of five chapters. Chapter two deals with definition of Six Sigma, its aim, benefits, reasons of success and failure. It also describes the literature reviewed in the areas of Six Sigma.

In Chapter three, Six Sigma methodology and tools used in this methodology are examined in detail.

In Chapter four, Six Sigma Project Selection methodology is explained and literature on Six Sigma project selection is reviewed in this section. In addition to these works, a case study about Six Sigma project selection in an automotive industry is presented.

Chapter five shows implementation of Six Sigma methodology which takes a successful implementation in an Aluminum Wheel production company in detail.

Finally, Chapter six summarizes the conclusion of the Six Sigma model and outlines directions for future research.

CHAPTER TWO
BACKGROUND OF SIX SIGMA

In this chapter, definition, benefits, success and failure reasons in Six Sigma are presented reviewing the literature. The relevant literature on Six Sigma applications are also presented in Sections 2.4 respectively.

2.1 What is Six Sigma?

Yang & Hsieh (2009) state that continuous improvement towards business performance excellence is the competitive edge for commercial firms to survive in highly competitive markets". Among the many business improvement approaches available, it is accepted that the Six-Sigma approach as one of the most effective methods.

Six Sigma can be defined as a discipline that involves Total Quality Management (TQM), strong customer focus, additional data analysis tools, financial results and project management (Anbari, 2002).

Basically Six Sigma is to rule out waste and to prevent the processes that create value for customer from mistakes. Treichler et al. (2002) state that Six Sigma is a highly disciplined philosophy that helps an organization to focus on developing and delivering near-perfect products and services. Six Sigma originates from the need to improve quality. Variation is accepted as the main cause of quality problems (Goh & Xie, 2004).

Standard Deviation is a statistical measure of distribution, spread, deviance and differentiation (heterogeneity). The more level of difference increases between the measured subjects under certain conditions, the more standard deviation becomes bigger. As the level of likeness (homogeneity) increases (the less differences), standard deviation gets smaller. A very progressive and extreme target in process control system is having 0 deviation systems and processes with no errors. In Quality terminology this target is referred as “zero error” or “zero tolerance” concept.

The Six Sigma methodology uses different statistical applications to measure and monitor performance. Using these quality management and statistical tools, a framework for process improvement can be furnished. Goh & Xie (2004) point out that Six Sigma translates an operational problem into a statistical problem, uses mathematical tools to solve it, and converts the results back to practical actions. Also Raisinghani et al. (2005) summarize that Six Sigma encompasses the methodology of problem solving, and focuses on optimization and cultural change. Using an extensive set of rigorous tools, uncompromising use of statistical and advanced mathematical tools, and a well defined methodology that produces significant results quickly Six Sigma fulfils this goal.

For the overall attainment of business excellence related financial and marketplace performance excellence, operational excellence is required. Klefsjo et al. (2001) point out that Six-Sigma is a tactical tool of great value in achieving operational excellence.

Six Sigma is more effective if it is used with other quality systems. Raisinghani et al. (2005) indicate that Six Sigma is a toolset, not a management system and is best used in conjunction with other more comprehensive quality standards such as the Baldrige Criteria for Performance Excellence or the European Quality Award.

Chiang & Chiao (2005) propose the unique features of the Six-Sigma approach are as follows:

1. Sequences and links improvement-tools into an overall approach (known as DMAIC),
2. Integration of the human and process elements for improvement using a belt-based organization (Belt-organization),
3. Attention to bottom-line results and the sustaining of gains over time.

Schroeder et al., (2007) identify five elements of these programs. First is management's involvement is very important in performing many Six Sigma functions. Second, improvement specialists and project implementers (e.g., Black Belt or Green Belt) are trained or hired at different Six Sigma competency levels. Third, Six Sigma programs have performance metrics and measurements based on cost, quality, and schedules (Keller, 2005). Fourth, Six Sigma implementation uses a systematic procedure; a five-step DMAIC (Define, Measure, Analyze, Improve, and Control) methodology. Fifth, project selection and prioritization is an important element of Six Sigma programs.

2.2 Objective and Benefits of Six Sigma

The main benefit of a Six Sigma program is the elimination of subjectivity in decision-making, by creating a system where everyone in the organization collects, analyzes, and displays data in a consistent way (Maleyeff & Kaminsky, 2002). Thus organizations provide continuous improvement using this systematic problem solving method. Six Sigma helps achieve the strategic goal of company.

On the way of attaining Operational excellence, Six Sigma elicits lots of benefit. A survey conducted by DynCorp showed that among all the process improvement techniques used in the last five decades, Six Sigma has clearly emerged as the most effective quality improvement technique (Dusharme, 2003).

Six Sigma uses a continuous improvement and problem solving methodology, which is consists of the phases: define, measure, analyze, improve and control. The main focus of Six Sigma is to reduce potential variability from processes and products by using this continuous improvement methodology (Banuelas et al., 2005).

Su & Chou (2008) summarize that with Six Sigma methodology, the benefits of an organization include not only higher levels of quality but also lower levels of costs, higher customer loyalty, better financial performance and profitability of business.

Chen et al. (2009) indicate that the methodology and tools of Six Sigma can be implemented to improve the quality of the product or service, when the variation of a part or a service does not meet the specifications of the internal or external customers.

Treville et al. (2008) suggest that "the causal relationships between constructs such as process capability improvement efforts, specification of improvement goals that are quantifiable and challenging, work facilitation, efforts to hear the voice of the customer, and so forth with outcome measures such as performance or customer satisfaction become more difficult to understand when viewed through the lens of Six Sigma. In other words, any theory that we construct that is grounded on Six Sigma will reduce sense making"(p22-23).

Schonberger (2008) considers that the objective of Six Sigma programs is to create a higher perceived value of the company's products and services in the eyes of the customer.

Objective of Six Sigma is improving quality of process capabilities more than the product quality. Thus the method that sustains excellence is to manage processes using different tools from traditional techniques. It is important to determine the relationships between inputs and outputs correctly to satisfy the customer needs and expectations. Process management has an important role to perform this objective, see Figure2.1. If we can represent the relationships between inputs and outputs a mathematical equation we can optimize the outputs.

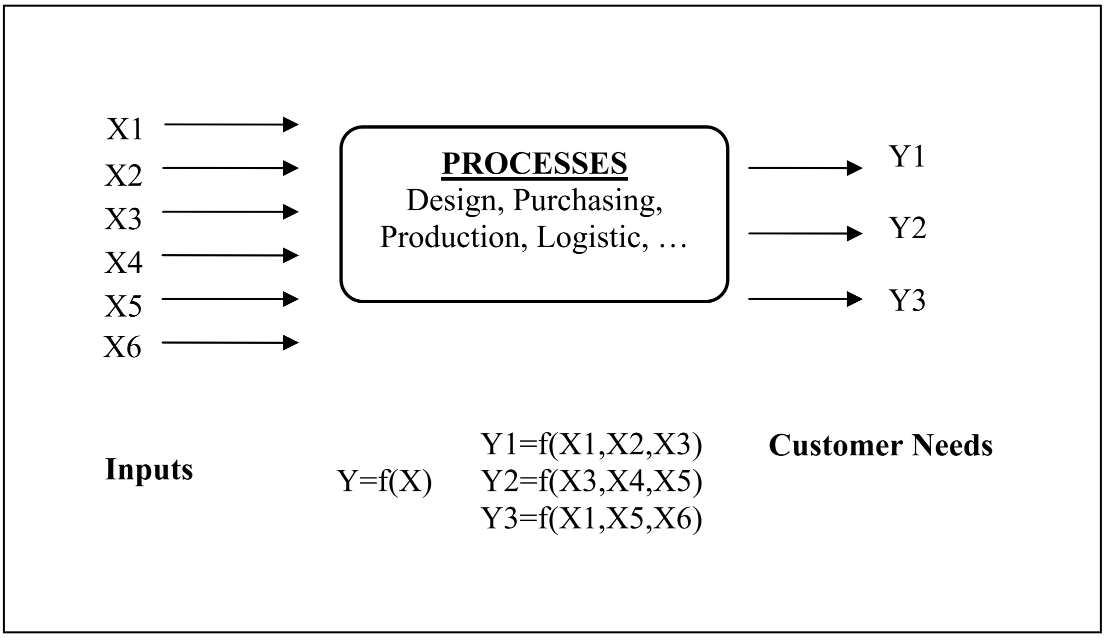

Figure 2.1 Process management

2.3 Success and Failure in Six Sigma

In the literature, it is expressed that the factors to gain success and reasons that causes failure.

Banuelas et al. (2005) introduce the success of this Six Sigma case study can be attributed to the following key factors:

1. Six Sigma methodology is an effective problem solving strategy;
2. Management involvement and commitment;
3. Project selection and its link to business goals;
4. Training and teamwork;
5. Project progress tracking and monitoring.

Raisinghani et al. (2005) point out that the success of this methodology within an organization has significant momentum that can only lead to fundamental organizational cultural transformation. The implementation of Six Sigma in any organization is at first difficult because it requires not only the buy in of senior management, but requires an active role of management in project definition and resource allocation.

To gain success in implementation of Six Sigma programs, understanding and leadership of management is very important. Management must guide along implementation process (Chakravorty, 2009).

Schon (2006) exhibits important Six Sigma success factors in the literature in the Table 2.1.

Table 2.1 Important Six Sigma success factors in the literature (Schon, 2006)

	Success factors	**Henderson & Evans (2000)**	**Goldstein (2001)**	**Pande et al. (2002)**	**Antony &Banuelas (2002)**	**Sandholm & Sörqvist (2002)**
1	The ongoing support and commitment of senior management	x	x	x	x	x
2	Focus on training and its content	x	x	x	x	x
3	Linking Six Sigma to the customer, human resources and suppliers	x		x	x	x
4	Organizational infrastructure	x		x	x	
5	Early communication to employees	x	x	x		
6	Project prioritization and selection		x		x	x
7	Understanding the Six Sigma methodology, tools and techniques	x		x	x	
8	Investing in adequate resources		x	x		x
9	Development of a uniform language and terminology			x		x
10	Development of a strategy to implement Six Sigma		x			x
11	Linking Six Sigma efforts to business strategy and priorities			x		
12	Focus on results			x		x
13	Follow-up and communicating success stories			x		x
14	Developing your own path to Six Sigma			x		x

Six Sigma helps achieve the strategic goal of company if the program reaches success. However, there are noticeable cases where Six Sigma failed to deliver the desired results. A survey conducted by the Aviation Week magazine among major aerospace companies reported that less than 50 percent of the companies expressed satisfaction with results from Six Sigma projects, nearly 30 percent were dissatisfied and around 20 percent were somewhat satisfied (Zimmerman & Weiss, 2005).

Six Sigma programs have value, but we can encounter the failed Six Sigma programs. Wurtzel (2008) tries to find why do so many Six Sigma programs fail? He argues that there is a lack on how to effectively guide the implementation of these programs.

Gopal (2008) reveals one of the reasons of failure in Six Sigma implementation in many companies is due to the lack of commitment from management.

Chakravorty (2009) indicates that one reason many Six Sigma programs fails is because an implementation model detailing the sequence of Six Sigma elements/activities is not available.

Keen (1997) points out the typical Six Sigma approach of jumping into processes and projects. Because of that reason it is not fully understood where the real benefits are for the organization. He argues that the definition of processes for each firm yields one of a kind answers and it takes time to identify them through a course of discovery.

Schneiderman (1999) states that he does not like Six Sigma because “It’s neither simple to understand nor, in most applications, an effective proxy for customer satisfaction.”

2.4 Related Literature

George (2002) states that implementing both six sigma and lean approaches is seen as an obvious and necessary step for companies to achieve simultaneous benefits from the both strategies. Also Thomas et al. (2009) introduce to develop and implement an integrated lean six sigma (LSS) model for manufacturing industry in their study.

The main phases of the integrated LSS approach are:

1. Define – what is the problem?

2. Measure – how is the process measured?
3. Analyze – what are the most important causes of defects?
4. Improve – how do we remove the causes of the defects?
5. Control – how can we maintain the improvements?
6. Implement 5S technique.
7. Application of value stream mapping (VSM).
8. Redesign to remove waste and improve value stream.
9. Redesign manufacturing system to achieve single unit flow (SUF).
10. Apply total productive maintenance (TPM) to support manufacturing functions (Thomas et al., 2009).

Goh & Xie (2004) describe that business leaders could well incorporate two additional Ss in the Six Sigma paradigm to make Six Sigma relevant and useful in the long term.

The first is the Systems Perspective. They considered that it helps drawing appropriate boundaries for Critical to Quality (CTQ) determination and improvement, combining potentially conflicting CTQs for an integrated approach, avoiding local sub-optimization, as well as providing macro-level assessments and reviews.

“The second is Strategic Analysis, with a substantial component of scenario planning aimed at anticipating changes, managing dynamic market demands, predicting novel lifestyles, seizing technological innovations, even promoting creativity and entrepreneurship”(p.238)(Goh & Xie, 2004).

By adding these two additional Ss it is not expected to reduce DPMO (defects per million) value or sigma level. These two Ss will bring in an organization additional capabilities for performance enhancement and business excellence:

NEEDED: Systems perspective
DESIRED: Strategic analysis

One of the positives of this paper considering dynamic business environment of the twenty-first century, additional requirements are determined and recommended to sustain excellence.

Scope of Six Sigma is defined on the micro level while the eight Ss scope is macro. Because of that reason Eight Ss focused on defined system not on a specific problem.

One of the disadvantages of eight Ss is improvement can be reached in the long term and results will be intangible. It is not obviously defined what are needed to be done to reach two additional Ss.

In the literature there are some case studies that shows the application of Six Sigma methodology. Tong et al. (2004) follow DMAIC procedures to effectively improve the quality of printed circuit board production where capability index is improved from 1.021 to 1.975. Raisinghani et al. (2005) argue on the Six Sigma methodology and showed how it fitted in with other quality initiatives. They show some case studies such as Motorola’s application, Allied signal’s application, GE’s application, Our Lady of Lourdes application. Li et al. (2006) introduce a CAE-based Six Sigma robust design procedure. This procedure significantly improves the reliability and robustness of the forming quality. It also increases design efficiency by using an approximate model for deep-drawing processes.

We can see Six Sigma that integrated with other philosophies like Lean Production, Total Quality Management or Supply Chain Management (SCM) in some studies. Yang et al. (2007) introduce a Six Sigma based methodology for the SCM area. This methodology is applied at Samsung Group. Management decides to implement this methodology because of these four key factors:

1. Project discipline: The analytical emphasis of Six Sigma will conduct the improvement projects to investigating and resolving root causes.

2. Sustaining results: By means of “control phase” of Six Sigma it is possible to ensure the improvements are sustained.
3. Well-established Human Resources framework: Six Sigma is seen as a proven framework for developing people.
4. Quantitative strength: Six Sigma uses quantitative analysis methods.

In this study an approach is termed DMAEV (define, measure, analyze, enable, and verify) is suggested. Yang et al. (2007) state that “The enable phase identifies ways to improve the ‘as-is’ and develops a plan for the ‘to-be’”. In this phase some tools like quality function deployment (QFD) or analytic hierarchy process (AHP) can be used. In the Verify phase a pilot test plan is established and then validation and verification the solution chosen in the Enable phase is performed (Yang et al., 2007). Six Sigma and SCM provide process innovation, quality improvement and synchronization of company’s value chain, from inbound logistics to sales and customer services.

One of the studies that denotes steps of DMAIC is belonged to Lo et al. (2009). The main objective of their study is to improve the quality of injection molded lenses with using DMAIC steps based on the Six Sigma approach. Firstly CTQ factors are determined according to customer requirements for quality.

In the Analyze section the Taguchi design-of-experiment method (DOE) is employed for screening relevant process parameters in the injection process. After completing the DOE procedures, confirmation experiments are conducted with selected combinations of factors and levels.

As a next step, an optimal set of factors and levels are taken during the mass-production processing conditions. In conclusion, the Six Sigma approach could effectively improve the upper process capability index Cpu from 0.57 to 1.75.

Using Taguchi method is one of the positive sides of their study. It provides identify the significant factors that influence the quality. It is not possible to produce trying all process parameters. Using Taguchi experimental method it is possible to identify and optimize the process parameters. Also it can be used as a reference for implementation of the Six Sigma approach for mentioned industry.

Chen et al. (2009) also study about optimization a process by using Taguchi-based Six Sigma approach. Taguchi parameter design is used to optimize plasma cutting process in an industry. Firstly they determine the factors and levels in the analyze phase and then data is captured in the measure phase. Taguchi experiment design testifies its effectiveness in achieving Six Sigma and lean paradigm with the reduced time and cost.

Another implementation model in the literature is belonged to Chakravorty (2009). Steps for the implementation are defined:

1. Perform strategic analysis driven by the market and the customer.
2. Establish a high-level, cross-functional team to drive the improvement initiative.
3. Identify overall improvement tools.
4. Perform high-level process mapping and to prioritize improvement opportunities.
5. Develop a detailed plan for low-level improvement teams,
6. Implement, document, and revise as needed. (Chakravorty, 2009)

Six Sigma methodology and case study are depicted verbally in Chakravorty's study. Pareto charts and graphs are only used to define and analyze the problem. This can be seen as a elementary approach.

Six Sigma seeks for continuous improvement for a process already exists. Design for Six Sigma (DFFS) approach tries to avoid process problems at the outset. Brue & Launsby (2003) identify DFSS as a systematic management technique that optimizes product, service, and procedure design through management tools, training sections, and evaluation methodologies such that customers' expectations and quality criteria can be reached. By globalization, shortening product development lifecycle becomes very vital for companies. New Product Development (NPD) procedure can meet the requirements of customers, demands on quality, time-to-delivery and cost limitations of a corporation. Jou et.al (2009) use Six Sigma to evaluate and improve the performance of NPD procedures. They use Six Sigma principle and adopt performance matrix, factor analysis, and theory of constraints in their study. They construct a new model on NPD procedure performance evaluation and improvement (Figure 2.3).

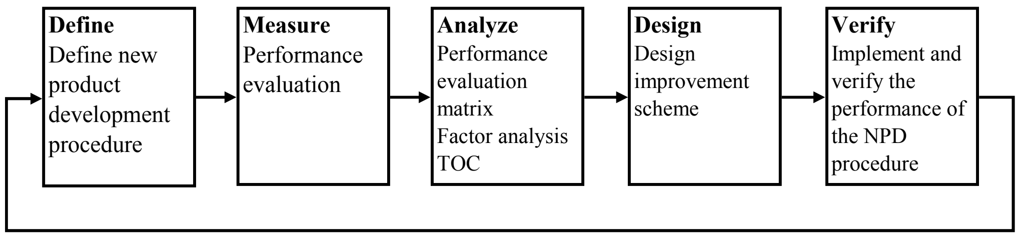

Figure 2.3 DFSS of NPD procedure performance evaluation study (Jou et al. 2009)

In the literature most papers have used descriptive research methodologies or empirical methodologies based on case studies or surveys. Although project selection is one of the most important phase of Six Sigma the literature on Six Sigma project evaluation and project selection is rare. Six Sigma applications have been studied in detail but without taking Six Sigma project selection into account.

In this thesis we study project selection and application together. Fuzzy AHP method is used for project selection. In project application these tools are used in the DMAIC phases: Voice of Customer (VOC), S.I.P.O.C., Failure Mode Effect Analysis (FMEA), Critical to Quality tree (CTQ), box plot and scatter plot analysis, hypothesis tests, Taguchi experimental design.

Table 2.3 displays the reviewed literature and summary of our study.

Table 2.3 Literature classification

		Coronado, R.B.& Antony, J. 2002	Goh, T.N. & Xie M. 2004	Tong J.P.C. Et al., 2004	Banuelas, R. Et al., 2005	Raisinghani, M. S. et al., 2005	Edgeman, R. Et al., 2005	Banuelas, R. Et al., 2006	Li, Y. Q., Et al., 2006	Schroeder, R.G., Et al., 2007	Kumar, U. et al., 2007	Yang H.M et al., 2007	Su, C. & Chou, C. 2008	Treville, S. Et al., 2008	Lo, W. C. et al., 2009	Chen, J. C. Et al., 2009	Yang, T. & Hsieh, C 2009	Chakravorty, S. S. 2009	Thomas, A. et al, 2009	Jou, Y.T. Et al., 2009	Büyüközkan G. & Öztürkcan D., 2010	Proposed Research
Six Sigma Approach	Definition	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+	-	+	+
	Failure&Success	+	-	-	+	-	-	+	-	-	+	-	+	+	-	-	+	+	-	-	-	+
	Objective	+	+	+	+	+	+	-	-	+	+	-	+	+	+	+	+	-	+	+	-	+
	Additional Approach for Six Sigma (Lean,Eight SS)	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-
Methodologies & Tools	DMAIC Cycle	-	+	+	+	+	+	-	+	+	-	+	+	+	+	+	-	+	+	+	-	+
	DOE (Design of Experiment)	-	-	+	-	+	-	-	+	-	-	-	-	-	+	+	-	-	+	-	-	+
	FMEA	-	-	-	-	+	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-
	Cause&Effect	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	ANOVA	-	-	+	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	+
	Value Stream Map	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Pareto Analysis	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	+
	Critical to Cost Tree	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
	QFD	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
	Control Charts	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+
	Taguchi Design	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+
	Factor Analysis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	Design for Six Sigma (DFSS)	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-
Project Selection	Project Selection	-	-	-	+	-	-	+	-	+	+	-	+	-	-	-	+	-	-	-	+	+
Project Selection Tools	Data Envelopment Analysis	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	Delphi Fuzzy Group Decision Making Method	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
	QFD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fuzzy Linear Reggression	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Fuzzy AHP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
	AHP	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	ANP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
	Decision Making Trial and Evaluation Laboratory	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Application	Conceptual	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Case Study	-	-	+	+	-	-	-	+	-	+	+	+	-	+	+	+	+	+	+	+	+

CHAPTER THREE
SIX SIGMA METHODOLOGY

There needs to be some inputs for creating an output and also it is necessary to come various reasons close together in to consist of the problem. Some of these reasons are very effective in the formation of the problem while others have less influence. The improvement studies without knowing which factors are the most effective in the creation of the problem are generally causes disappointment. Because while everyone supposes that the problem would disappear, it will arise again due to unimprovement of the real root reason. Traditional approaches to problem solving with method of trial and error eliminate the reasons because of experience, so it will takes too long and costly to reach a permanent solution.

The purpose of this chapter is to explain Six Sigma methodology (DMAIC). In Section 3.1 to 3.5 the tools that can be used for every phase will be summarized.

Six Sigma is considered to provide a structured methodology, often referred to as DMAIC (Define, Measure, Analyze, Improve and Control)

DMAIC method, in addition to experience, with a predominantly data-based, systematic and disciplined approach helps to analyze the problems and find the root reasons. Thus it would be able to solve the problem at the lowest cost and optimum point that provides highest return.

3.1 Define Phase

In the define phase, the problem is determined, and customer impact and potential benefits of the project are assessed (Goh & Xie, 2004). Aim and scope of the project is also defined in this phase.

The key measurable characteristics of a product or process must be identified for achieving company goals. These characteristics are Critical to Quality (CTQs). Chou

& Chao (2007) exhibit that the average CTQ capability increases, the capability of the corresponding process increases, make it further achieve strategic business goals.

The Six Sigma team ensures that the following outputs are achieved end of the define phase. They can proceed to the next phase if these outputs are achieved:

Process linked to strategic business requirements;

- Customer and critical-to-quality characteristics identified;
- Linkage of customer requirements to process outputs;
- Team formed with charter describing purpose, project plan, goals and benefits of the project;
- Financial benefits identified and calculated (Banuelas et al., 2005).

The tools that can be used in the define phase:

- S.I.P.O.C (Supplier, Inputs, Process, Outputs, Customer)
- Shareholder Analysis
- Product Analysis
- Voice of Customer
- Affinity Diagram
- Critical to Quality Tree Diagram

3.1.1 Voice of Customer

The "voice of the customer" is a process used to capture the requirements/feedback from the customer (internal or external) to provide the customers with the best in class service/product quality. This process is all about being proactive and constantly innovative to capture the changing requirements of the customers with time.

Sometimes requirements can be very specific for instance tolerances, limits, targets…etc. However sometimes they can be very general: "This computer opens very late", "Cargo is delivered with damage"…etc.

Steps of Voice of the Customer:

1. Determine the customers and expectations of these customers
2. Collect the feedback data and analyze this data
   -Methods of collect data: customer complaints, feedbacks, service breakdown data, consumer advisory services
3. Listing the important ones from analyzed data. (Listing the requirements of the customer – affinity diagram can be used)
4. Represent customer requirements as CTQs

VOC plays a key role to increase of customer satisfaction.

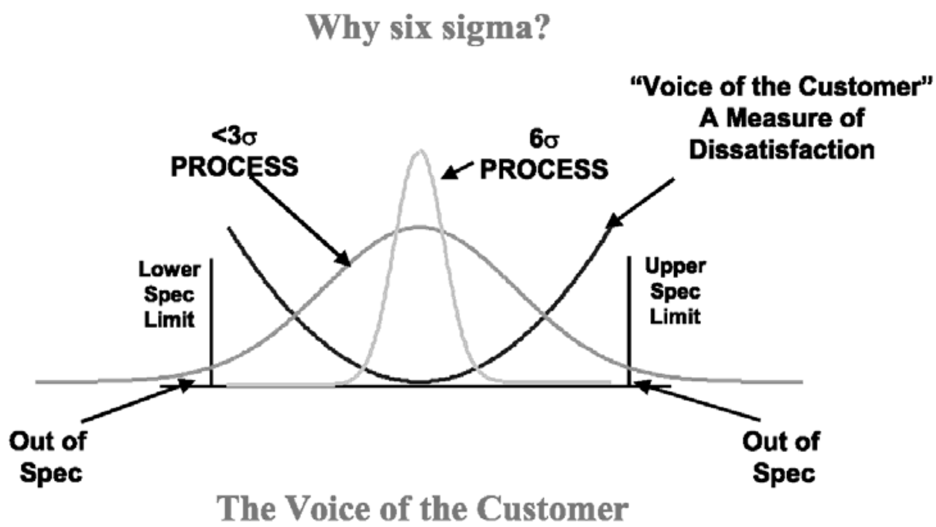

Figure 3.1 VOC effect on customer satisfaction

3.1.2 Critical to Quality Tree Diagram

The Critical-to-Quality Tree or ***CTQ Tree*** is the tool for transforming customer requirements into measurable data. The CTQ Tree decomposes wide customer requirements into more easily quantified requirements. Once specific Critical to

Quality requirements have been obtained, products or service measurements can be compared to them quantitatively.

The advantages of using a CTQ Tree are:

- Translating broad customer needs into quantified requirements
- Helping Sigma teams move from general to detailed specifications
- Making certain that all aspects of the customer requirement are identified.

In Figure 3.2, CTQ Tree diagram can be seen for a cargo sample. Aim of this sample is to define the CTQs that have effect on the cost and failures in cargo service.

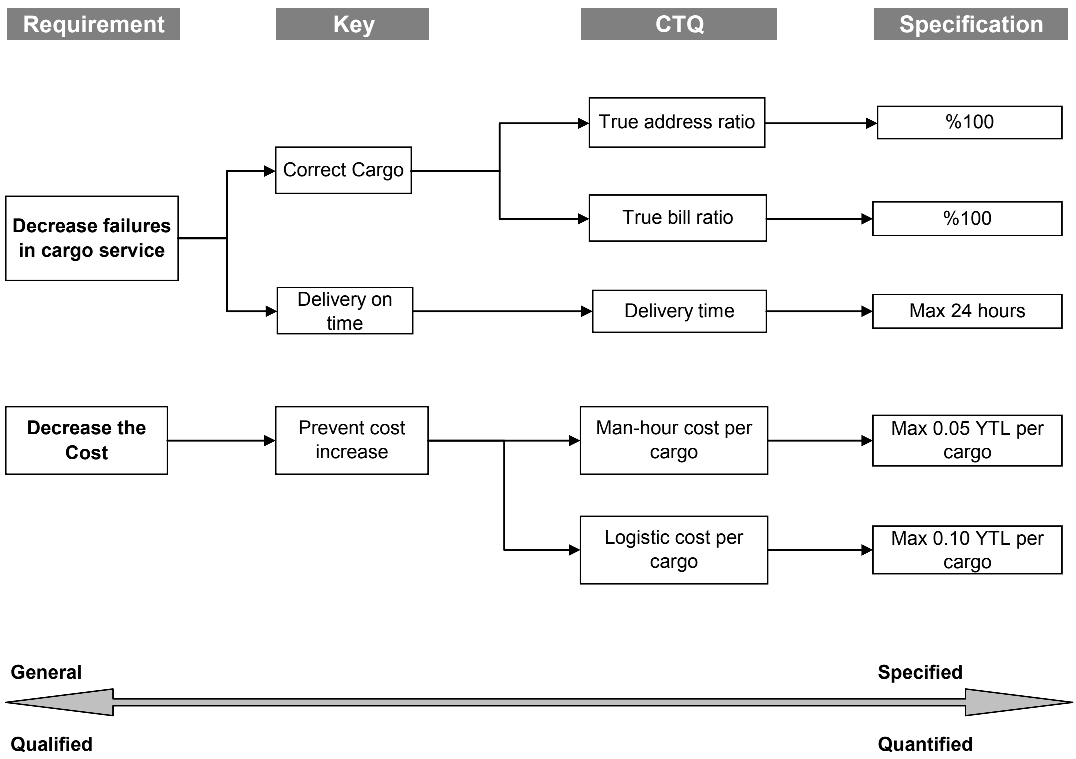

Figure 3.2 A sample for CTQ tree diagram

3.1.3 S.I.P.O.C Diagram

A SIPOC diagram is a tool used by a team to identify all relevant elements of a process improvement project before work begins. It helps define a complex project that may not be well scoped.

The SIPOC diagram includes a high-level map of the process that "maps out" its basic steps. Through the process, the suppliers (S) provide input (I) to the process. The process (P) your team is improving adds value, resulting in output (O) that meets or exceeds the customer (C) expectations (Figure 3.3).

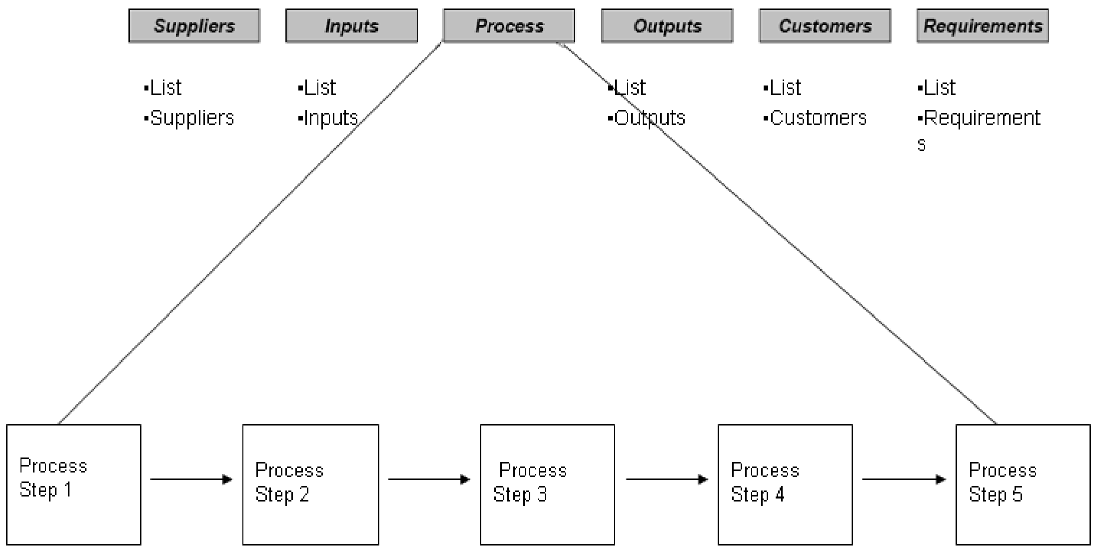

Figure 3.3 S.I.P.O.C diagram

3.1.4 Prioritization Matrix

Prioritization Matrix analytically explains the relationship between the input determined in the process step and the output of the process itself. Importance degrees are assigned to customer expectations (CTQs) and relationships between the process inputs and these expectations are scored. The inputs with the highest scores are evaluated for the next steps or given priority in data collection.

Prioritization Matrix is used to prioritize complex or unclear issues, where there are multiple criteria for deciding importance. It is useful to determine which process inputs must be focused for meeting the CTQs. Besides Prioritization Matrix has a big role to determine which process inputs (cause) have effects on which process outputs (effect).

A sample for prioritization matrice can be seen in Table 3.1.

Table 3.1 Prioritization matrice

Prioritization Matrice			Output1	Output2	
			10	8	Degree of Importance
Nr	**Process Step**	**INPUTS**			**TOTAL**
1	A	Input1			
2	A	Input2			
3	B	Input3			
4	B	Input4			

3.2 Measure Phase

In the measure phase, CTQs of the product or service are identified, measurement capability is certained, and current performance levels as well as improvement goals are decided (Goh & Xie, 2004).

The purpose of this phase is to collect data that will give an understanding of the nature of the problem.

Collected data provides:

- Differences between reality and theory
- Affirmation of past experiences
- Shows beginning performance
- Shows relations cause variance

There are some tools that may be used in this phase: data collection plan, measurement system analysis, capability analysis, control charts…etc.

Before data collection a *Data Collection Plan* must be done. Data collection plan shows data types, standard methods for data collection, initial and target values for every factor.

Accuracy of the collected data is very important because all decisions are made according to the analysis using this collected data. *Gage R&R* is the tool used to quantify the level of variation in the measurement process. Gage R&R, which stands for gage repeatability and reproducibility, is a statistical tool that measures the amount of variation in the measurement system arising from the measurement device and the people taking the measurement. Repeatability is defined as a measure of how well one can obtain the same beholded value when measuring the same part or sample over and over using the same measuring device. Reproducibility is the closeness of agreement between independent results obtained with the same method on identical test material but under different conditions (different operators, different apparatus, different laboratories and/or after different intervals of time).

After deciding the measurement system is capable another important thing for measure phase is to understand the capability of current process. *Capability Analysis* is a useful tool in gaining an understanding of the current process. It is used to determine how well a process meets a set of specification limits is called a process capability analysis.

Banuelas et al., (2005) state that after the completion of the measure phase the team achieves the following:

- Plan for collecting data that specifies the data type and collection technique;
- Validated measurement system that ensures repeatability and reproducibility;

- Set of preliminary analysis results that provides project direction;
- Baseline measurement of current performance.

3.3 Analyze Phase

In the analyze phase, data gathered from the measurement phase are interpreted and root causes of defects are discovered. Key process variables can be identified if they link to defects.

Measure phase exhibits basic performance values of the process. Theories about the root causes of the problem will be developed and affirmated using data in the analyze phase. In conclusion root causes of the problem will be defined. If accuracy of these causes can be proven they will be a basis for solutions.

End of the analysis phase, the Six Sigma team members had a strong understanding of the factors impacting their project, including:

- Key process input variables or the vital few ‘X’ that impact the ‘Y ’;
- Sources of variation (i.e. where the greatest degree of variation exists) (Banuelas et al., 2005).

In this phase these tools can be used:

- Cause and Effect Diagrams
- Brainstorming
- Box plot diagrams
- FMEA
- Design of Experiment (DOE)
- Scatter plot diagrams

3.3.1 Box plot Diagrams

A box plot or is a convenient way of graphically depicting groups of numerical data through their five-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum) (Figure 3.4).

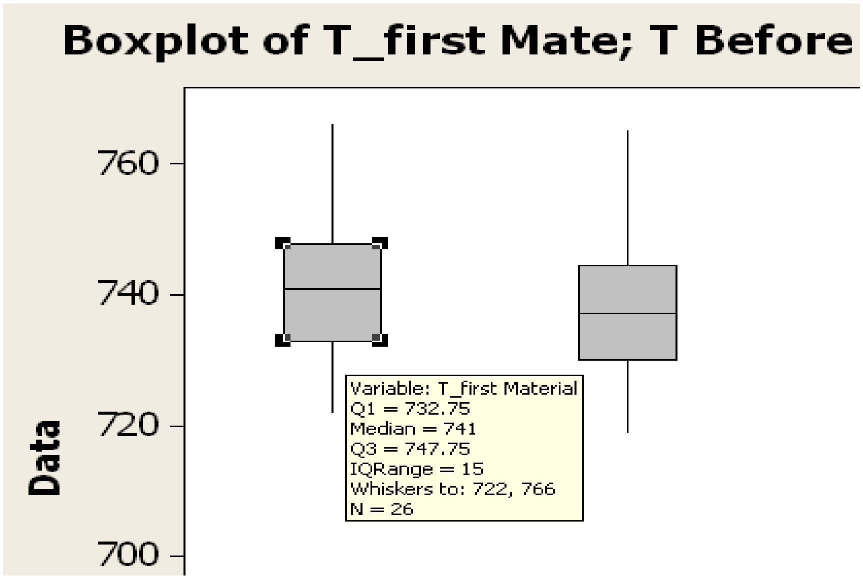

Figure 3.4 A sample for box plot

Box plots have these advantages:

- Easy to understand at a glance
- Provide some indication of the data's symmetry and skewness
- Shows outliers
- By using a box plot for each categorical variable side by side on the same graph, one quickly can compare data sets.

3.3.2 Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is an analytical technique that combines the technology and experience of people in identifying foreseeable failure modes of a product or process and planning for its elimination (TQM, Prentice Hall).

The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEA improves product/process reliability and quality and increase customer satisfaction. Early identification and elimination of potential product/process failure modes are possible so FMEA minimizes late changes and associated cost.

Types of FMEA:

- System - focuses on global system functions
- Design - focuses on components and subsystems
- Process - focuses on manufacturing and assembly processes
- Service - focuses on service functions
- Software - focuses on software functions

An example for a FMEA form can be seen in Table 3.2.

Table 3.2 FMEA form

<table>
<tr><td colspan="17">FAILURE MODE AND EFFECT ANALYSIS
(DESIGN FMEA)
FMEA Number :
Page : 1 of 1
Item :   Design Responsibility :   Prepared By
Model Number / Year :   Key Date :   FMEA Date (Orig.) :   Rev. :
Core Team :</td></tr>
<tr><th rowspan="2">Item / Function</th><th rowspan="2">Potential Failure Mode</th><th rowspan="2">Potential Effects of Failure</th><th rowspan="2">S</th><th rowspan="2">CLASS</th><th rowspan="2">Potential Causes / Mechanisms of Failure</th><th rowspan="2">O</th><th rowspan="2">Current Design Controls</th><th rowspan="2">D</th><th rowspan="2">RPN</th><th rowspan="2">Recommended Actions</th><th rowspan="2">Responsibility and Target Completion Dates</th><th colspan="5">Action Results</th></tr>
<tr><th>Actions Taken</th><th>SEV</th><th>OCC</th><th>DET</th><th>RPN</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

FMEA evaluates the risk of potential failures identified for each subsystem or component (Su & Chou, 2007). The risk priority number (RPN) is determined by three risk parameters which are:

Severity (S): Severity is the assessment of the seriousness of the effect of the potential failure mode to the next component, sub-system, system. Severity is rated on a 1 to 10 scale, with a 1 being none and a 10 being the most severe (Table3.3).

Table 3.3 Severity ranking table

EFFECT	SEVERITY OF EFFECT	RANKING
Hazardous without warning	May endanger machine or assembly operator. Failure will occur without warning	10
Hazardous with warning	Failure will occur with warning	9
Very High	Major disruption to production line. Customer very dissatisfied	8
High	Minor disruption to production line. A portion of product may have to be sorted and scrapped. Customer dissatisfied.	7
Moderate	Minor disruption to production line.Customer experiences discomfort	6
Low	Minor disruption to production line. %100 of product may have to be reworked. Customer experiences some dissatisfaction	5
Very Low	Minor disruption to production line. Defect noticed by customer	4
Minor	Minor disruption to production line. Defect noticed by average customer	3
Very Minor	Minor disruption to production line. Defect noticed by discriminating customer.	2
None	No effect	1

Occurrence (O): Occurrence is the chance that one of the specific causes/mechanisms will occur. Occurrence is rated based on a 1 to 10 scale (Table 3.4).

Table 3.4 Occurrence ranking table

PROBABILITY OF FAILURE	POSSIBLE FAILURE RATES	RANKING
Very high : Failure is almost inevitable	> 1 in 2	10
	1 in 3	9
High: Generally associated with processes similar to previous processes that have often failed.	1 in 8	8
	1 in 20	7
Moderate: Generally associated with processes similar to previous processes that have experienced occasional failures.	1 in 80 1 in 400 1 in 2,000	6 5 4
Low: Isolated failures associated with similar processes.	1 in 15,000	3
Very Low	1 in 150,000	2
Remote: Failure is unlikely	< 1 in 1,500,000	1

Detection (D): Detection is a relative measure of the assessment of the ability of the design control to detect either a potential cause/mechanism or the subsequent failure mode before the component, sub-system, or system is completed for production. It is rated based on a 1 to 10 scale, with a 1 being almost certain and a 10 being absolute uncertainty (Table3.5).

Table 3.5 Detection ranking table

DETECTION	LIKELIHOOD OF DETECTION BY PROCESS CONTROL	RANKING
Absolutely Impossible	No known controls available to detect failure mode	10
Very Remote	Very remote likelihood current controls will detect failure	9
Remote	Remote likelihood current controls will detect failure mode	8
Very Low	Very low likelihood current controls will detect failure mode	7
Low	Low likelihood current controls will detect failure mode	6
Moderate	Moderate likelihood current controls will detect failure mode	5
Moderately High	Moderately high likelihood current controls will detect failure mode	4
High	High likelihood current controls will detect failure mode	3
Very High	Very high likelihood current controls will detect failure mode	2
Almost Certain	Current controls almost certain to detect the failure mode.	1

Risk Priority Number (RPN): RPN is calculated as follows:

$$RPN = (S) * (O) * (D) \tag{3.1}$$

For concerns with a relatively high RPN, the engineering team must make efforts to take corrective actions.

3.3.3 Design of Experiment (DOE) and Taguchi Parameter Design

Experimentation is used to see behaviors of the process and data collection. If the process is composed of one or two inputs simple experimentation is adequate. When the process involves several inputs that may have interactions, a Design of Experiment (DOE) is required to explore the relationship of the output to the inputs. A DOE is a structured, organized method for determining the relationship between factors (Xs) affecting a process and the output of that process (Y).

With many factors and levels it is time and money consuming to make all experiments. For this reason a more economical DOE approach is required to resolve industrial problems cost-effectively and in a timely manner. Taguchi parameter design, which is capable of providing the optimal solution with reduced number of experiment runs, is one of them (Chen et al., 2009). Dr. Genichi Taguchi's approach to finding which factors effect a product in a Design of Experiments can dramatically reduce the number of trails required to gather necessary data. An orthogonal array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. A parameter is an independent variable that may influence the final product, whereas a level is a distinction within that parameter.

Taguchi divided the factors affecting any system into two categories - control factors and noise factors. Control factors are factors affecting a system that are easily set by the experimenter. Noise factors are factors affecting a system that are difficult or impossible to control. The process of making a system insensitive to noise factors is referred to as *Robust Design* (http://www.weibull.com/DOEWeb).

Taguchi's approach gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Taguchi method is the combination of Design of Experiments with optimization of control parameters to obtain best results.

Selection of orthogonal arrays:

- Number of factors
- Number of levels for each factors
- Resolution of the experiment

Standard demonstration : $\mathbf{L_a(b^c)}$ **L :** Latin square

a : number of experiment **b :** number of levels **c :** number of factors

Table 3.6 shows that how orthogonal arrays can be chosen.

Table 3.6 Selection tables for orthogonal arrays (cell values are resolutions)

Selection of Two Level Orthogonal Array

	Number of factors with two levels																
Orthogonal array	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
L4	4		1	Not possible													
L8			4	2	1												
L16				4	3	2			1								
L32					4	3	2										1
L64						4	3	2									
L128							4	3									
L256								4	3	2							

Selection of Three Level Orthogonal Array

	Number of factors with three levels							
Orthogonal array	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
L9	4		1		Not possible			
L18	1							
L27	4			2	1			

Table 3.7 An example of L9 array

L9 Standard Array				
	Column no			
Trial no	**1**	**2**	**3**	**4**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

After selection of appropriate orthogonal array experiments are performed. Results of every experiment are written on the right part of orthogonal array. Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

S/N ratios for every experiment combinations are calculated as follows:

S/N = [Useful Output / Harmful Output] = $\frac{\bar{y}^2}{\sigma^2}$

$$\bar{y} = \frac{\sum_{\forall j} y_j}{n} = \frac{y_1 + y_2 + \ldots + y_n}{n} \tag{3.2}$$

$$\sigma = \sqrt{\frac{\sum_{\forall j}\left(y_j - \bar{y}\right)^2}{n-1}} = \sqrt{\frac{\left(y_1 - \bar{y}\right)^2 + \left(y_2 - \bar{y}\right)^2 + \ldots + \left(y_n - \bar{y}\right)^2}{n-1}} \tag{3.3}$$

$$S/N = \eta = 10 \times \log\left[\frac{\bar{y}^2}{\sigma^2}\right] \tag{3.4}$$

Table 3.8 shows that the results of experiments and calculated S/N and variances.

Table 3.8 Result of the experiments

	A	B	C	D	E1	E2	E3	E4	σ	$\bar{y}$	S/N
L9	**1**	**2**	**3**	**4**							
1	1	1	1	1					σ_1	μ_1	$(S/N)_1$
2	1	2	2	2					σ_2	μ_2	$(S/N)_2$
3	1	3	3	3		Results of every experiments			σ_3	μ_3	$(S/N)_3$
4	2	1	2	3					σ_4	μ_4	$(S/N)_4$
5	2	2	3	1					σ_5	μ_5	$(S/N)_5$
6	2	3	1	2					σ_6	μ_6	$(S/N)_6$
7	3	1	3	2					σ_7	μ_7	$(S/N)_7$
8	3	2	1	3					σ_8	μ_8	$(S/N)_8$
9	3	3	2	1					σ_9	μ_9	$(S/N)_9$

Once these S/N ratios and mean values are calculated for each factor and level, they are tabulated as shown in the Table 3.9.

Table 3.9 Output table format for S/N ratios or means

Level	A	B	C	D
1	A_1	B_1	C_1	D_1
2	A_2	B_2	C_2	D_2
3	A_3	B_3	C_3	D_3
Δ	Δ_A	Δ_B	Δ_C	Δ_D

As an example values in the table are calculated as follows:

$A_1 = (S/N_1 + S/N_2 + S/N_3) / 3$ (for S/N ratio table) (3.5)

$A_1 = (\mu_1 + \mu_2 + \mu_3) / 3$ (for μ table) (3.6)

$B_2 = (S/N_2 + S/N_5 + S/N_8) / 3$ (for S/N ratio table)

$B_2 = (\mu_2 + \mu_5 + \mu_8) / 3$ (for μ table)

$\Delta_C = \max\{C_1, C_2, C_3\} - \min\{C_1, C_2, C_3)$ (3.7)

After preparing the tables for S/N ratios and means, these values are showed in the output graphs. Graphs for S/N ratios and means are used to find optimum solution. Most of the factors are decided considering the S/N ratio graphs. S/N ratio graph is used for decreasing the variation. The higher S/N ratio for each factor is selected (Figure 3.5). Means output graph is used for undecided factors. Values that are close to the average is selected using the means table.

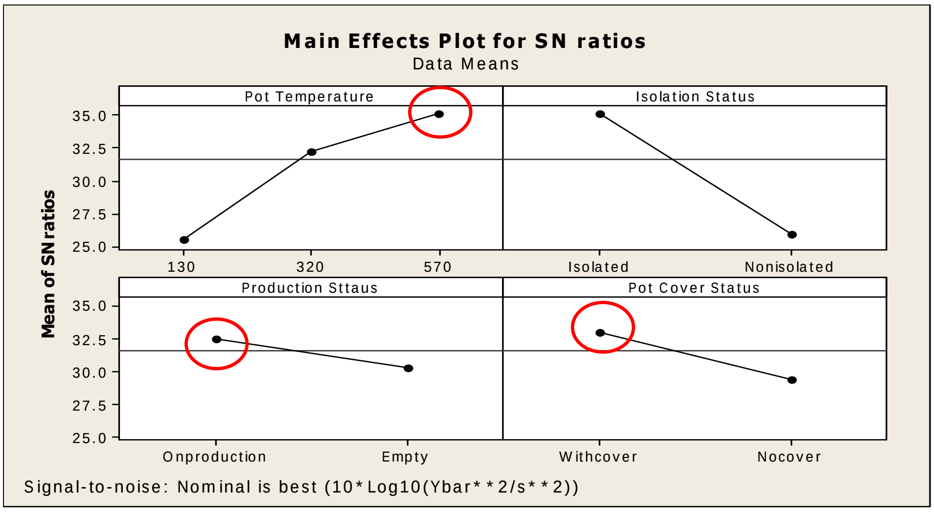

Figure 3.5 Sample graph for S/N ratios

3.3.4 Scatter Plots

A scatter plot, also called a scatter diagram, is a basic graphic tool that illustrates the relationship between two variables. The variable that might be considered an explanatory variable is plotted on the x axis, and the response variable is plotted on the y axis. Scatter plots are used with variable data to study possible relationships between two different variables. Even though a scatter plot depicts a relationship between variables, it does not indicate a cause and effect relationship. It is a tool used to visually determine whether a potential relationship exists between an input and an outcome.

3.4 Improve Phase

In the improve phase, Goh & Xie (2004) state that the affects of key process variables on the CTQs are quantified, within range limits of these variables are identified, and the process modified to reduce CTQ defect levels. The objective of this phase is to consider the causes found in the analysis phase and also selecting the solutions to eliminate such causes.

In this phase these tools can be used:

- Brainstorming
- FMEA
- Setup Reduction
- 5S
- DOE
- Kaizen
- Hypothesis Tests

At the conclusion of the improve phase, the Six Sigma team accomplishes these outputs:

- Identification of alternative improvement;
- Implementation of the best alternative for improving the process;
- Validation of the improvement (Banuelas et al., 2005).

3.4.1 Hypothesis Tests

A statistical hypothesis test is a method of making statistical decisions using experimental data. Hypothesis testing refers to the process of using statistical analysis to determine if the observed differences between two or more samples are due to random chance (null hypothesis) or to true differences in the samples (alternate hypothesis). A null hypothesis (H_0) is a stated assumption that there is no difference in parameters (mean, variance, DPMO) for two or more populations. The alternate hypothesis (Ha) is a statement that the observed difference or relationship between two populations is real and not the result of chance or an error in sampling.

Hypothesis testing is the process of using a variety of statistical tools to analyze data and, ultimately, to fail to reject or reject the null hypothesis. From a practical point of view, finding statistical evidence that the null hypothesis is false allows you to reject the null hypothesis and accept the alternate hypothesis.

α - *Risk :* For simple hypotheses, this is the test's probability of *incorrectly* rejecting the null hypothesis. If the risk level is low, we think that it is safe to accept the alternate hypothesis.

p value : The p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. One often rejects a null hypothesis if the p-value is less than 0.05 or 0.01.

Table 3.10 shows that the selection of Hypothesis tests.

Table 3.10 Selection of hypothesis tests

	According to a target	**Confidence Interval**	**Comparison of 2 factors**	**Comparison of more than 2 factors**
Means	T	T	T	ANOVA
Variances	X^2	X^2	F, Levene	Bartlett, Levene
Qualitative Data	One Proportion, X^2	One Proportion, X^2	Two Proportion, X^2	X^2

3.4.1.1 T-Test

The t-test evaluates whether the means of two groups are *statistically* different from each other. This analysis is suitable whenever you want to compare the means of two groups.

$H_0 : \mu = \mu_0$
$Ha : \mu \neq \mu_0$

T Test can be used under these circumstances:

- Comparing a sample mean to an accepted value
- Comparing two sample means

3.4.1.2 F-Test

The F-test is used to comparison of standard deviations. Normality of data must be controlled before the tests. If the distributions are normal, F-test can be used.

$H_0 : \sigma_1 = \sigma_2$

$Ha : \sigma_1 \neq \sigma_2$

3.5 Control Phase

Control phase is very important for Six Sigma methodology. In this phase, gains that are made in the improve phase are evaluated and try to develop and implement methods of control that will maintain the gains. Goh & Xie (2004) indicate that actions are taken to sustain the improved level of performance and make certain long-term gains in the control phase. We ensure that the processes continue to work well, produce desired output results, and maintain quality levels.

Documented and implemented control plan, standardized process, documented procedures, response plan established and deployed project closure are outputs of this phase.

3.5.1 Control Plan

One of the most important outputs is control plan. A control plan corresponds with shop floor what parameters to monitor, and how to react if a problem is found. The Control Plan is one part of ensuring the gains are maintained. If process performance strays out of control there are details and tools to adjust and re-monitor to ensure there has not been an over adjustment.

3.5.2 Quality Control Process Charts

In all production processes, we need to monitor the extent to which our products meet specifications. In the most general terms, there are two "enemies" of product quality: (1) deviations from target specifications, and (2) excessive variability around target specifications. The most common method of control is Statistical Process Control (SPC).

SPC Charts are used to analyze process performance by plotting data points, control limits, and a centerline. A process should be in control to assess the process capability.

If a single quality characteristic has been measured from a sample, the control chart shows the value of the quality characteristic versus the sample number or versus time. In general, the chart contains a center line that represents the mean value for the in-control process. Two other horizontal lines, upper control limit (UCL) and the lower control limits (LCL), are also shown on the chart. These control limits are chosen so that almost all of the data points will fall within these limits as long as the process remains in-control.

3.5.2.1 Individuals Moving Range (I – MR) Charts:

This chart shows individual observations on one chart associated with another chart of the range of the individual observations normally from each sequent data point. This chart is used for continuous types of data.

Each data point for Moving Range (MR) Chart plots the difference (range) between two sequent data points as they come from the process in sequential order. The Individuals (I) Chart plots each measurement as a separate data point. Therefore there will be one less data point in the MR chart than the Individuals chart.

I-MR charts should be in control according the control tests. There are many types of tests that can determine control and points within the control limits can also be out of control or special cause.

3.5.3 Standardization

Standardization provides to perform works using the best way. Standardization enables processes to go as smoothly as possible. In a manufacturing environment, the value of standardization has been proven over and over.

Standardization allows high quality production of goods and services on a reliable, predictable, and sustainable basis. This is making sure that important elements of a process are performed consistently in the most effective method. Changes are made only when data shows that a new alternative is better.

Use of standard practices will reduce variation among individuals or groups and make process output more predictable and also gives direction in the case of different conditions.

Standardization provides:

- “Know-Why” for operators and managers now on the job
- A basis for training new people
- A hint for tracing problems
- A means to capture and keep knowledge

CHAPTER FOUR
SIX SIGMA PROJECT SELECTION

One of the most difficult aspects of Six Sigma is the selection of the improvement projects. Project selection is very important decision because of the fact that these projects require different resources (capital, labor etc.). Project selection is a multi-criteria decision making (MCDM) problem and requires a lot of evaluation criteria.

Section 4.1 presents Six Sigma project selection and applications in the literature. In section 4.2 Fuzzy logic and Fuzzy Analytic Hierarch Process (FAHP) is explained. Reviewed literature about FAHP is given in section 4.3. In this study Chang's extent analysis method is used for project selection. This method is presented in Section 4.4. In section 4.5, a case study from automotive industry is presented to prove the proposed FAHP approach applicability and validity.

4.1 Literature on Six Sigma Project Selection

Six Sigma implementation can have negative consequences if applied in the wrong project. Therefore project selection is very important achieving success for organizations.

For many companies, generally the question is whether or not to implement Six Sigma. It is more important how to implement a successful six sigma process improvement project. The selection of process improvement projects is probably the most difficult aspect of Six Sigma (Pande et al., 2000; Snee, 2001).

Project selection is the process of evaluating individual projects or groups of projects, and then choosing and prioritizing to implement some of them so that the objectives of the organization will be achieved (Meredith & Mantel, 2003).

Execution and evaluation in the context of an organization’s overall goals and mission is essential avoiding wasted effort or to make an effort really worthwhile, a wider systems perspective in project selection (Goh & Xie, 2004).

Su & Chou (2008) state that the project selection is the one of the most critical success factors for the effective deployment of a Six Sigma program. It helps accomplish the company’s strategic goal through the effective use of project-driven approach. Six Sigma projects must be linked with business strategy and should meet the customer requirements. Because of Six Sigma is a project-driven methodology, it is necessary to prioritize projects which provide maximum financial benefits to the organization (Coronado & Antony, 2002). It is often challenging for a company making the decision for project selection to maximize the financial outcomes (Yang & Hsieh, 2009).

Linking the projects with the business strategy some of these problems will occur due to the responsibility over the projects is scattered in different departments. Also Su & Chou (2008) point out another concern is how to select the critical Six Sigma projects under the finite organization’s resources? It is very important in achieving success of Six Sigma implementation to deploy the organization’s strategic goal into possible projects.

Pande et al. (2000) indicate that there should not be too many factors in project selection. Instead of many criteria choosing the five to eight that are the most relevant criteria for the organization would be sufficient. In Six Sigma initiative, although there are many criteria on which to judge the performance of Six Sigma projects, for instance, net cost savings, cost of poor quality, capacity, and customer satisfaction it still lacks to have an standard and unanimous rule for selecting or prioritizing of those projects. Therefore, the risk and benefits can be considered the dimensions to be used for selecting and prioritizing Six Sigma projects (Harry & Schroeder, 2000).

Snee (2001) states good Six Sigma projects must possess some characteristics that are connected to business objectives, major importance to the organization, reasonable scope, etc. Gijo & Rao (2005) consider the Six Sigma projects must be selected to parallel with the organization's goal and objectives; in addition, selection of suitable belt projects plays an important role in successful Six Sigma implementation.

Banuelas et al. (2005) employ the cause-and-effect matrix to list all potential projects that are likely to affect the outputs of the process. The criteria used in this evaluating process are quality, waste and runtime.

Su & Chou (2008) try to group the projects from two dimension considering their project benefits and project risk. The projects can be figured as a map. The project map shows as Figure 2.2.

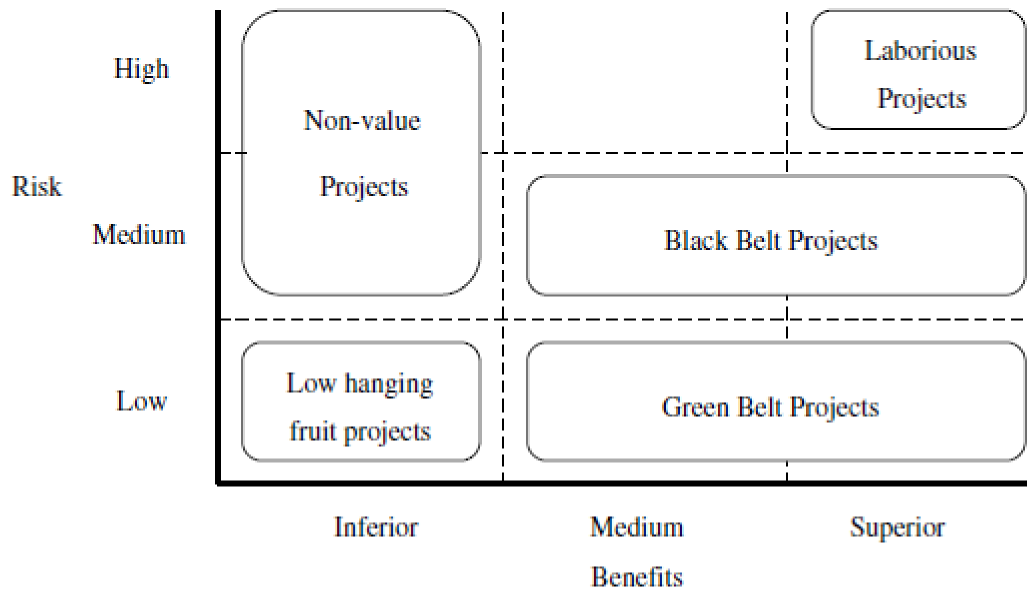

Figure 2.2 Project map (Su & Chou, 2008)

Another work which is belonged to Breygogle (1999) about project selection criteria displays four dimensions of the balanced score card, namely financial, customer, internal business process and learning, and growth. Also Mark (2001) considers financial performances for project selection. Furthermore he stated that projects should focus on activities critical to quality (CTQ).

Pande et al. (2000) classify six sigma project selection criteria into three categories:

1. “Business benefits criteria;
2. Feasibility criteria; and
3. Organization impact criteria.”

Harry & Schroeder (2000) summarize the following criteria for six sigma project selection:

1. “Defects per million opportunities (DPMO);
2. Net cost savings;
3. COPQ;
4. Cycle time;
5. Customer satisfaction;
6. Capacity; and
7. Internal performance.”

Snee & Rodebaugh (2002) exhibit four key phases to development of the project selection process. Those phases include:

1. Identify Black Belt projects;
2. Create a project hopper;
3. Examine the project portfolio;
4. Create an improvement system.

Banuelas et al. (2006) suggest the following six criteria as critical for six sigma project selection:

1. “Customer impact;
2. Financial impact;
3. Top management commitment;
4. Measurable and feasible;
5. Learning and growth; and
6. Connected to business strategy and core competence.”

Seetharaman et al. (2006) find that a national quality award winner also showed improved performance in both sales and revenue. Therefore, national quality award criteria should be a potential framework for the Six-Sigma project selection criteria.

There are many studies that were proposed a variety of models of Six Sigma project selection, prioritization procedures, and tools (e.g., Breyfogle et al., 2001; Adams et al., 2003; Kumar et al., 2007).

Management is always interested in identifying the projects which result in the maximum benefit to the organization. Table 2.2 provides the list of tools used for six sigma project selection (Banuelas et al., 2006).

Table 2.2 Methods used for selection of six sigma projects (Banuelas et al., 2006)

Author	**Tool(s)**
Pyzdek (2000, 2003)	Pareto priority index (PPI), AHP, QFD, theory of constraints (TOC)
Breyfogle et al. (2001)	Project assessment matrix
Pande et al. (2000)	QFD
Kelly (2002)	Project selection matrix
Adams et al. (2003)	Project ranking matrix
Larson (2003)	Pareto analysis
De Fao and Barnard (2004)	Reviewing data on potential projects against specific criteria
Dinesh Kumar et al. (2006)	AHP

Source : Banuelas et al. (2006)

In the literature there are some case studies that analyze the project selection process. In the study of Banuelas et al. (2005), they illustrate the effective use of Six Sigma to reduce waste in a coating process. In their study they describe in detail Project selection process and how the Six Sigma methodology is applied. By this paper it is possible to see various tools and techniques within Six Sigma methodology.

For project selection process pareto plot and gap analysis are used only. Project selection is very important to achieve success in Six Sigma. Financial outcomes, company's strategic goals, risks, benefits…, etc. must be evaluated for project selection. It is a negative part to use only pareto plot to select a project. Using more quantitative tools in projects selection provides more accurate results.

Kumar et al. (2007) use Data Envelopment Analysis (DEA) as a tool for six sigma project selection in their research. The purpose of their study is to develop a mathematical model and select one or more Six Sigma projects that improve overall customer satisfaction and maximize benefit to the organization.

Firstly they identify the important inputs and outputs for six sigma projects then using DEA they identify projects that result in maximum benefit.

Kumar et al. (2007) point out DEA was often used for relative efficiency analysis and productivity analysis, was successfully constructed for six sigma project selection.

DEA uses linear programming (LP) to obtain an effective, non-parametric efficiency measure. DEA has the capacity to compare the multiple inputs and output parameters at the same time, so that a scalar measure of overall performance is obtained (Kumar et al., 2007). Thus it is an advantage for project selection process using DEA to reach maximum benefit.

In the suggested DEA models, three inputs and five outputs are used. The input and output criteria used in the DEA model represents most of the project selection criteria reported in the literature.

The inputs are:

1. Project cost;
2. Project duration; and
3. Number of Black and Green Belts.

The outputs are:

1. Customer satisfaction;
2. Impact on business strategy;
3. Increase in sigma level;
4. Financial impact (impact on COPQ); and
5. Increase in productivity (Kumar et al., 2007)

After defining inputs and outputs an example study is done extensively. Kumar et al. (2007) use expected values of input and output values. As a conclusion of their research the feasible projects are determined and ranked according to their benefits.

Generally it is thought that the project selection is a multi-criteria decision-making (MCDM) problem. Because of that reason in the literature most tools use some parametric model that assigns a priori weights to project inputs and outputs. Kumar et al., (2007) point out that solution obtained using parametric methods are very sensitive to a priori weights assigned to the inputs and outputs. DEA is a non-parametric method, and does not assume a priori weights for inputs and outputs.

Another tool can be used for MCDM problems is Analytic Hierarchy Process (AHP). A case study is studied by Su & Chou (2008) using AHP in a semiconductor foundry. The aim of their study is to guide to create critical Six Sigma projects and identify the priority of these projects. Firstly, the projects are created considering organization’s business strategic policies and voice of customer (VOC).

Each customer evaluate the products or services using a five-point scale, where A is excellent, B is good, C is acceptable, D is fair, and E is unacceptable. By gathering this data company realizes the weak sides. Some projects are generated according to VOCs and company's strategic goals.

Secondly, AHP model is implemented to evaluate the benefits of each project. AHP is a powerful and flexible tool for multiple criteria decision-making. Su & Chou (2008) point out that AHP enables decomposition of a problem into a hierarchy and makes the best decision that involves the comparison of decision elements.

After implementation AHP, a hierarchical failure mode effects analysis (FMEA) is also developed to evaluate the risk of each project. Possible projects are decomposed into subsystems and for each subsystem, FMEA is performed by engineers. Benefits of these projects are evaluated too.

Su & Chou (2008) describe the value of RPNoverall is used as the criteria for evaluating the project risk. If the value of RPNoverall is lower than 100, the project qualifies as low risk. The medium risk is the value of RPNoverall approximately between 100 and 150. As the value of RPNoverall is higher than 150, it will be classified as a high risk project.

Finally each project is grouped into Green Belt, Black Belt or other projects based on the project benefits and RPNs.

Project selection process is well defined in this study. Using AHP a systematic methodology is employed to generate the projects considering company's strategic policies. Unquantifiable information, incomplete information, partial ignorance may cause difficulty. Fuzzy set theory for the decision-making process can eliminate these difficulties.

Yang & Hsieh (2009) study to adopt national quality award criteria as the Six-Sigma Project selection criteria, moreover proposed a hierarchical criteria evaluation process. In this study management team use a Delphi fuzzy multiple criteria decision making method to evaluate the strategic criteria. Then Six Sigma Champion evaluates the tactical sub-criteria which contained additional operational issues.

In their study Yang & Hsieh (2009) follow three steps while the project selection process:

1. “The group decision-making for the top level criteria,
2. The sub-criteria evaluation by Champion,
3. The aggregated project ranking for the project selection decision.”

Using fuzzy multiple criteria decision-making method, they determine the project rankings.

Positive side of their study is using FMCDM (Fuzzy Multiple Criteria Decision-Making) to project selection process. Because of the fact that human opinions are often in conflict in a fuzzy environment this methods have been developed due to indetermination in assessing the criteria. To resolve this difficulty, fuzzy set theory has been used for the decision-making process (Bellman & Zadeh, 1970). In this study proposed methodology is showed in detail.

More recently Büyükozkan & Öztürkcan (2010) study to combine two multi-criteria decision making methods, Decision Making Trial and Evaluation Laboratory (DEMATEL) and analytic network process (ANP) to effectively identify the most appropriate project alternative especially in logistics companies.

Büyükozkan & Öztürkcan (2010) propose DEMATEL to detect complex relationships and build relation structure among criteria for selecting Six Sigma projects. Additionally they use ANP to deal with the problem of the subsystems interdependence and feedback; set priorities among goal, strategy and criteria and to determine the most appropriate project alternative. They categorize criteria under three strategies (business excellence, revenue growth, and productivity), four factors (benefits, opportunities, risks, costs) and a total number of 14 sub-factors. Integrating these two techniques as a combined MCDM approach is a wise option which can be regarded as a consolidated new tool considering inner dependency and weights of criteria (Büyükozkan & Öztürkcan, 2010).

4.2 Fuzzy Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is one of the best ways for making a decision among complex criteria. AHP is an Eigen value approach to the pair-wise comparisons. Vaidya & Kumar (2006) pointed out that AHP supplies a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances. The scale ranges from 1/9 for “least valued than”, to 1 for “equal”, and to 9 for “absolutely more important than” covering the entire spectrum of the comparison.

These are the steps for AHP methodology:

1st Step: Definition of problem and state the objectives and outcomes
2nd Step: Hierarchical structure with criteria and alternatives
3rd Step: employ pair wise comparisons and form comparison matrices
4th Step: Compare each factor and adjust them on the numerical scale
5th Step: Find Eigen value, Consistency Index (CI), Consistency Ratio (CR), and normalized values for each criteria. Control if consistency property of matrices is in a desire range
6th Step: Combine the relative weights of criteria to obtain an overall rating for the alternatives

Kahraman (2008) indicates that the application of the classic MCDM method may face serious practical constraints, because of the criteria containing imprecision or vagueness inherent in the information. For many MCDM Methods it is not easy to express all criteria quantitavely or using linguistic terms. Chang (1996) considered that the traditional AHP does not take into account the uncertainty associated with the mapping of one’s perception (or judgment) to a number. It is more appropriate to use the fuzzy set theory in dealing with uncertainty. Using fuzzy set theory with a useful tool it helps us to deal with the vagueness while evaluation of data.

In this study Fuzzy Analytic Hierarchy Process is used for the Six Sigma Project selection.

Fuzzy set theory, which was founded by Zadeh (1965), has emerged as a powerful way of representing quantitatively and manipulating the imprecision in decision-making problems. Fuzzy sets or fuzzy numbers can appropriately represent imprecise parameters, and can be manipulated through different operations on fuzzy sets or fuzzy numbers. Using these fuzzy sets and numbers, the process will be more powerful and its results more credible.

4.2.1 Fuzzy Set

Let X be a universe of discourse, $\tilde{A}$ is a fuzzy subset of X such that for all $x \in X$. There is a number $\mu_{\tilde{A}}(x) \in [0,1]$ which is assigned to represent the membership of x to $\tilde{A}$ and $\mu_{\tilde{A}}(x)$ is called the membership function of $\tilde{A}$.

4.2.2 Fuzzy Number

A fuzzy number $\tilde{A}$ is a normal and convex fuzzy subset of X. Convex set implies that

$$\forall x_1 \in X,\ x_2 \in X,\ \ \forall \alpha \in [0,1],$$

$$\mu_{\tilde{A}}(ax_1 + (1-a)x_2) \geq \min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2))$$

4.2.3 Triangular Fuzzy Number

A Triangular Fuzzy Number (TFN) $\tilde{A}$ can be defined by a triplet (a,b,c). Equation 4.1 shows that the membership function

$$\mu_{\tilde{A}}(x)=\begin{cases}\dfrac{x-a}{b-a}, & a\le x\le b,\\ \dfrac{c-x}{c-b}, & b\le x\le c,\\ 0, & otherwise.\end{cases} \tag{4.1}$$

Addition: $\oplus$

$$(a_1,b_1,c_1)\oplus(a_2,b_2,c_2)=(a_1+a_2,b_1+b_2,c_1+c_2) \tag{4.2}$$

Multiplication: $\otimes$

$$(a_1,b_1,c_1)\otimes(a_2,b_2,c_2)=(a_1\times a_2,b_1\times b_2,c_1\times c_2) \tag{4.3}$$

Fuzzy Analytical Hierarchy Process (FAHP) method is a systematic approach to the decision making problems by using the concepts of fuzzy set theory and hierarchical structure analysis. Each performance criteria can be specified by the decision maker, related to its importance. In the FAHP method, the pair-wise comparisons in the judgment matrix are fuzzy numbers and use fuzzy arithmetic and fuzzy aggregation operators, the procedure calculates a sequence of weight vectors that will be used to choose main attribute.

Using triangular fuzzy numbers with traditional AHP improves the degree of judgment of decision maker. The central value of a fuzzy number is the corresponding real crisp value. The spread of the number is the estimation from the real crisp number. If decision maker cannot specify their preferences by numerical values, he/she can also specify preferences in the form of natural language expressions about the importance of each performance attribute (Güngör et al., 2009). Using fuzzy numbers and arithmetic a sequence of weight vectors are calculated. These weight vectors are used to combine the scores on each criterion.

4.3 Literature Review for Fuzzy Analytical Hierarchy Process

While making a decision some of the decision criteria can be strictly assessed while others cannot. The judgments of humans are corresponded by linguistic and indefinite patterns. Yu (2002) indicates that good decision making models should be able to tolerate vagueness or ambiguity because fuzziness and vagueness are common characteristics in many decision making problems. Fuzziness of human decision making must be taken into account. The Fuzzy AHP is an advanced analytical method developed from the traditional AHP.

Fuzzy Analytic Hierarchy Process can be used as a project selection methodology. In the project selection section 4.4 Fuzzy AHP is used for Six Sigma project selection considered in this thesis.

Van Laarhoven and Pedrycz (1983) make the earliest work in fuzzy AHP. They compare fuzzy ratios described by triangular membership functions.

Chang (1996) introduces a new approach for fuzzy AHP which is called Chang's extent analysis method. Using triangular fuzzy numbers for pair-wise comparison scale off fuzzy AHP and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons.

Stam et al. (1996) show that artificial intelligence techniques can be used to determine or judge the selection ratings in AHP. They resolved that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative multi-criteria decision problems with indefinite or fuzzy ratio-scale selection judgments.

Cheng (1997) proposes a new algorithm for evaluating naval tactical missile systems by the fuzzy analytical hierarchy process based on grade value of membership function.

Cheng et al. (1999) proposes a new method for evaluating weapon systems by analytical hierarchy process based on linguistic variable weight.

Kahraman et al. (2004) use Chang's (1996) extent analysis method to select the best Turkish catering firm providing the most customer satisfaction. The fuzzy analytic hierarchy process is used to compare three Turkish catering firms in their paper.

Huang et al. (2006) use fuzzy analytic hierarchy process method and utilize crisp judgment matrix to evaluate subjective expert judgments. In their study they use a Fuzzy Analytic Hierarchy Process in government-sponsored R&D projects.

As a conclusion they exhibited some advantages:

1. AHP helps decision-makers to decompose decision problems for forming hierarchical decision structure.
2. The fuzzy approach helps to formulate judgment vagueness
3. The simulation process helps to understand how expert judgments change in different decision risks by incorporating the degree of optimism.
4. The fuzzy AHP helps to resolve disparity among experts. (Huang et al., 2006)

Lee (2008) uses a Fuzzy AHP model considering benefits, opportunities, costs and risks (BOCR) for supplier selection. For the BOCR concept there are criteria that are opposite in direction to other criteria, such as benefits (B) versus costs (C), and opportunities (O) versus risks (R).

In the literature many Fuzzy AHP methods are proposed. The main topic of all these methods is to represent systematic approaches in decision making problems using the fuzzy set theory and hierarchical structure analysis. In this study Chang's (1996) extent analysis is used for project selection.

4.4 Chang's (1996) Extent Analysis Method

Chang (1996) uses triangular fuzzy numbers for the bilateral comparison scale of AHP. Chang's approach is less time taking and less computational expense than many other fuzzy AHP approaches, besides it can overcome the deficiencies of traditional AHP (Lee, 2008). Chan & Kumar (2007) state that this approach not only can adequately handle the inherent uncertainty and imprecision of the human decision making process but also can provide the robustness and flexibility needed for the decision maker to understand the decision problem.

Let $X = \{x_1, x_2, ...x_n\}$ be an object set and $U = \{u_1, u_2, ..., u_m\}$ be a goal set. Chang (1992) identified each goal, g_i, is performed, according to extent analysis.

For each object, m extent analysis values can be obtained. These extent analysis values are showed with the following signs:

$$M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^m \qquad i = 1,2,3,...,n$$

All the $M_{gi}^j \, (j = 1,2,...,m)$ are triangular fuzzy numbers.

Steps of Chang's extent analysis:

Step 1: The fuzzy synthetic extent with respect to with respect to ith object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{4.4}$$

Equation (4.5) shows the fuzzy addition operation of m extent analysis value to obtain $\sum_{j=1}^{m} M_{gi}^j$

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_i , \sum_{j=1}^{m} m_i , \sum_{j=1}^{m} u_i \right) \tag{4.5}$$

To obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$ perform the inverse of the vector in Equation (4.6) and Equation (4.7) is computed.

$$\sum_{i=1}^{n} \sum_{j=1}^{m} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \tag{4.6}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i} , \frac{1}{\sum_{i=1}^{n} m_i} , \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{4.7}$$

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min \left(\mu_{M_1}(x), \mu_{M_2}(y) \right) \right] \tag{4.8}$$

Equation (4.8) can be expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad I_1 \geq u_2 \\ \dfrac{I_1 - u_2}{(m_2 - u_2) - (m_1 - I_1)}, & otherwise \end{cases} \tag{4.9}$$

Equally we can express $V(M_2 \geq M_1)$ as seen in Figure 4.1 where d is the ordinate of highest intersection point D between μ_{M1} and μ_{M2}.

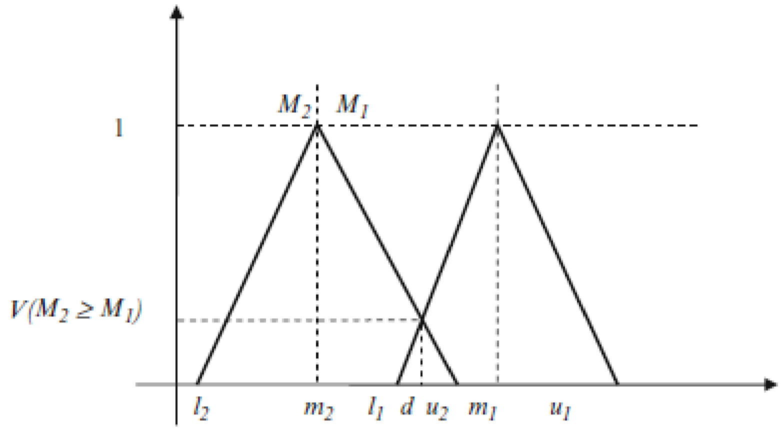

Figure 4.1 The intersection between M_1 and M_2

Step 3: The degree of possibility for a convex fuzzy number to be greater than *k* convex fuzzy numbers M_i = (i = 1,2,...,k) can be defined by

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) and (M \geq M_2) and \ldots and (M \geq M_k)]$$
$$= \min V(M \geq M_i), \qquad i = 1,2\ldots,k \tag{4.10}$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$ (4.11)

For k = 1,2,...,n; $k \neq i$ Weight vector is given by the Equation (4.12)

$$W' = (d'(A_1), d'(A'_2), \ldots, d'(A_n))^T \tag{4.12}$$

where A_i(i = 1,2,...,n) are n elements.

Step 4: After normalization, the normalized weight vectors are

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad \text{where W is a nonfuzzy number} \tag{4.13}$$

4.5 An Application on Six Sigma Project Selection Using Fuzzy AHP Method

Three projects were assigned by the management team for 2009. Fuzzy AHP method is used to select which project is more beneficial to the company.

Three project candidates:

Project A: Balance Rework Decrease
Project B: Optimization of Material Transferring Heat Loss
Project C: Shortening Heat Treatment Process Time

Criteria and sub-criteria were determined for project selection. Figure 4.2 shows that main and sub-criteria.

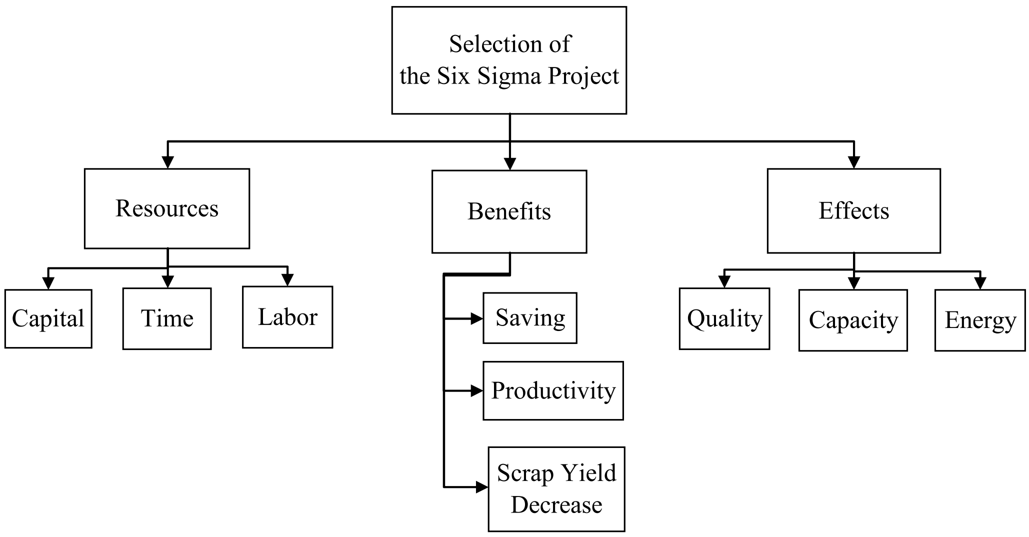

Figure 4.2 Criteria and sub-criteria for project selection

Chang (1996) develop a scale including Triangular Fuzzy Numbers (TFN). This scale is given in Table 4.1.

Table 4.1 TFN scale (Chang, 1996)

Statement	TFN
Absolute	(7/2, 4, 9/2)
Very Strong	(5/2, 3, 7/2)
Fairly Strong	(3/2, 2, 5/2)
Weak	(2/3, 1, 3/2)
Equal	(1, 1, 1)

Firstly project selection team evaluated the main criteria using this TFN scale. The fuzzy evaluation matrix with respect to the goal can be seen in Table 4.2.

Table 4.2 The fuzzy evaluation matrix with respect to goal

	Resources	Benefits	Effects
Resources	(1, 1, 1)	(0.67, 1, 1.5)	(1.5, 2, 2.5)
Benefits	(1.5, 2, 2.5)	(1, 1, 1)	(2.5, 3, 3.5)
Effects	(0.67, 1, 1.5)	(0.67, 1, 1.5)	(1, 1, 1)

Step1: Obtain Equation 4.4, Equation 4.5 and Equation 4.6 were calculated as follows:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_i , \sum_{j=1}^{m} m_i , \sum_{j=1}^{m} u_i \right)$$

M_r = (1 + 0.67 + 1.50 , 1 + 1 + 2 , 1 + 1.50 + 2.50)

M_r = (3.17, 4, 5)

M_b = (1.50 + 1 + 2.5 , 2 + 1 + 3 , 2.5 + 1 + 3.5)

M_b = (5, 6, 7)

Me = (2.33, 3, 4)

$$\sum_{i=1}^{n} \sum_{j=1}^{m} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \text{ (1/16, 1/13, 1/10,50) = (0.06, 0.08, 0.10)}$$

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$$

Using Equation 4.4:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$$

Sr = (3.17, 4, 5) X (0.06, 0.08, 0.10) = (0.20, 0.31, 0.48)

Sb = (5, 6, 7) X (0.06, 0.08, 0.10) = (0.31, 0.46, 0.67)

Se = (2.33, 3, 4) X (0.06, 0.08, 0.10) = (0.15, 0.23, 0.38)

Step 2: Comparisons for $V(M_2 \geq M_1)$ were done and using Equation 4.9 vector values were calculated.

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1, & if(m_2 \geq m_1) \\ 0, & if(l_1 \geq u_2) \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases}$$

Table 4.3 S matrices showing l,m,u values

	L	M	U
Sr	0.20	0.31	0.48
Sb	0.31	0.46	0.67
Se	0.15	0.23	0.38

For instance V (Sr>= Sb)

$m_r = 0.31$ $m_b = 0.46$ $m_2 \geq m_1$ equation was not provided

$l_b = 0.31$ $u_r = 0.48$ $l_1 \geq u_2$ equation was not provided

V (Sr>= Sb) = 0.52 was calculated using the equation.

V (Sr>= Sb) = 0.52

V (Sr>= Se) = 1

V (Sb>= Sr) = 1

V (Sb>= Se) = 1

V (Se>= Sr) = 0.61

V (Se>= Sb) = 0.23

Step 3: Weight vector was obtained using Equation 4.10 and 4.12

W' = ((min(V(Sr>=Sb), V (Sr>= Se)), (min(V (Sb>= Sr), V (Sb>= Se)),
(min(V (Se>= Sr)),

W' = $(0.52, 1, 0.23)^T$

Step 4: After normalization weight vector for goal was

Wgoal = $(0.30, 0.57, 0.13)^T$

That means that resources has an importance of %30, benefits has an importance of %57 while effects has an importance of %13 on goal.

After obtaining the Weight vector for main criteria, sub-criteria evaluation will be done. Table 4.4 shows the evaluation of the sub-criteria of *Resources*.

Table 4.4 Evaluation of the sub-criteria with respect to resources

	Capital	**Time**	**Labor**
Capital	(1, 1, 1)	(3.5, 4, 4.5)	(1.5, 2, 2.5)
Time	(0.67, 1, 1.5)	(1, 1, 1)	(0.67, 1, 1.5)
Labor	(0.67, 1, 1.5)	(1.5, 2, 2.5)	(1, 1, 1)

In a similar way W' and normalized weight vector values were calculated.

Scapital = (0.50, 0.67, 0.87)

Stime = (0.24, 0.33, 0.48)

Slabor = (0.19, 0.29, 0.43)

V (Scapital>= Stime) = 1

V (Scapital>= Slabor) = 1

V (Stime>= Scapital) = 0

V (Stime>= Slabor) = 0.69

V (Slabor>= Scapital) = 0.28

V (Slabor>= Stime) = 1

$W' = (1, 0, 0.28)^T$ with normalization $W_R = (0.78, 0, 0.22)^T$

Evaluation of the sub-criteria with respect to *Benefits* is given in Table 4.5.

Table 4.5 Evaluation of the sub-criteria with respect to benefits

	Saving	**Productivity**	**Scrap Yield Decrease**
Saving	(1, 1, 1)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
Productivity	(0.67, 1, 1.5)	(1, 1, 1)	(1.5, 2, 2.5)
Scrap Y. Dec.	(0.67, 1, 1.5)	(0.67, 1, 1.5)	(1, 1, 1)

Ssav = (0.39, 0.53, 0.72)

Sp = (0.18, 0.27, 0.40)

Sscr = (0.13, 0.20, 0.32)

V(Ssav>Sp) = 1 , V(Ssav>Sscr) = 1 , V(Sp>Ssav) = 0.04

V(Sp>Sscr) = 1 , V(Sscr>Ssav) = 0 , V(Sscr>Sp) = 0.68

$W' = (1, 0.04, 0)^T$ with normalization $W_B = (0.96, 0.04, 0)^T$

Evaluation of the sub-criteria with respect to *Effects* is given in Table 4.6.

Table 4.6 Evaluation of the sub-criteria with respect to effects

	Quality	**Capacity**	**Energy**
Quality	(1, 1, 1)	(1.5, 2, 2.5)	(0.67, 1, 1.5)
Capacity	(0.67, 1, 1.5)	(1, 1, 1)	(0.67, 1, 1.5)
Energy	(2.5, 3, 3.5)	(1.5, 2, 2.5)	(1, 1, 1)

Sq = (0.20, 0.31, 0.48)

Sc = (0.15, 0.23, 0.38)

Se = (0.31, 0.46, 0.67)

$V(Sq>Sc) = 1$, $V(Sq>Se) = 0.52$, $V(Sc>Sq) = 0.70$

$V(Sc>Se) = 0.23$, $V(Se>Sq) = 1$, $V(Se>Sc) = 1$

$W' = (0.52, 0.23, 1)^T$ with normalization $W_E = (0.30, 0.13, 0.57)^T$

After finding weight vectors for main criteria and sub-criteria, projects were evaluated according to sub-criteria. Evaluations of the projects with respect to sub criteria are shown in the tables 4.7 to 4.15.

Table 4.7 Evaluation of the projects with respect to capital

	Project A	**Project B**	**Project C**
Project A	(1, 1, 1)	(0.67, 1, 1.5)	(1.5, 2, 2.5)
Project B	(2.5, 3, 3.5)	(1, 1, 1)	(3.5, 4, 4.5)
Project C	(0.67, 1, 1.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector: $W_{capital} = (0.04, 0.96, 0.0)^T$

Table 4.8 Evaluation of the projects with respect to time

	Project A	**Project B**	**Project C**
Project A	(1, 1, 1)	(0.67, 1, 1.5)	(0.67, 1, 1.5)
Project B	(2.5, 3, 3.5)	(1, 1, 1)	(1.5, 2, 2.5)
Project C	(1.5, 2, 2.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{time} = (0.13, 0.57, 0.30)^T$

Table 4.9 Evaluation of the projects with respect to labor

	Project A	**Project B**	**Project C**
Project A	(1, 1, 1)	(0.67, 1, 1.5)	(0.67, 1, 1.5)
Project B	(2.5, 3, 3.5)	(1, 1, 1)	(1.5, 2, 2.5)
Project C	(1.5, 2, 2.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{labor} = (0.13, 0.57, 0.30)^T$

Table 4.10 Evaluation of the projects with respect to saving

	Project A	Project B	Project C
Project A	(1, 1, 1)	(0.67, 1, 1.5)	(1.5, 2, 2.5)
Project B	(2.5, 3, 3.5)	(1, 1, 1)	(3.5, 4, 4.5)
Project C	(0.67, 1, 1.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{saving} = (0.04, 0.96, 0)^T$

Table 4.11 Evaluation of the projects with respect to productivity

	Project A	Project B	Project C
Project A	(1, 1, 1)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
Project B	(0.67, 1, 1.5)	(1, 1, 1)	(0.67, 1, 1.5)
Project C	(0.67, 1, 1.5)	(1.5, 2, 2.5)	(1, 1, 1)

Normalized weight vector : $W_{productivity} = (0.45, 0.21, 0.34)^T$

Table 4.12 Evaluation of the projects with respect to scrap yield decrease

	Project A	Project B	Project C
Project A	(1, 1, 1)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
Project B	(0.67, 1, 1.5)	(1, 1, 1)	(1.5, 2, 2.5)
Project C	(0.67, 1, 1.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{scrap} = (0.96, 0.04, 0)^T$

Table 4.13 Evaluation of the projects with respect to quality

	Project A	Project B	Project C
Project A	(1, 1, 1)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
Project B	(0.67, 1, 1.5)	(1, 1, 1)	(1.5, 2, 2.5)
Project C	(0.67, 1, 1.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{quality} = (0.96, 0.04, 0)^T$

Table 4.14 Evaluation of the projects with respect to capacity

	Project A	Project B	Project C
Project A	(1, 1, 1)	(0.67, 1, 1.5)	(0.67, 1, 1.5)
Project B	(2.5, 3, 3.5)	(1, 1, 1)	(1.5, 2, 2.5)
Project C	(1.5, 2, 2.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{capacity} = (0.13, 0.57, 0.30)^T$

Table 4.15 Evaluation of the projects with respect to energy

	Project A	Project B	Project C
Project A	(1, 1, 1)	(0.67, 1, 1.5)	(0.67, 1, 1.5)
Project B	(3.5, 4, 4.5)	(1, 1, 1)	(2.5, 3, 3.5)
Project C	(2.5, 3, 3.5)	(0.67, 1, 1.5)	(1, 1, 1)

Normalized weight vector : $W_{energy} = (0.0, 0.78, 0.22)^T$

As a last evaluation all priority weights for sub criteria, criteria and projects are shown in Table 4.16.

Table 4.16 Last evaluation of projects

Sub-attributes of Resources				**Priority weight**
	Capital	**Time**	**Labor**	
Weight	0.78	0	0.22	
ProjectA	0.04	0.13	0.13	**0.06**
ProjectB	0.96	0.57	0.57	**0.87**
ProjectC	0	0.3	0.3	**0.07**
Sub-attributes of Benefits				**Priority weight**
	Saving	**Prod**	**Scrap Y.**	
Weight	0.96	0.04	0	
ProjectA	0.04	0.45	0.96	**0.06**
ProjectB	0.96	0.21	0.04	**0.93**
ProjectC	0	0.34	0	**0.01**
Sub-attributes of Effects				**Priority weight**
	Quality	**Capacity**	**Energy**	
Weight	0.3	0.13	0.57	
ProjectA	0.96	0.13	0	**0.30**
ProjectB	0.04	0.57	0.78	**0.53**
ProjectC	0	0.3	0.22	**0.16**
Main attributes				**Priority weight**
	Resources	**Benefits**	**Effects**	
Weight	0.3	0.57	0.13	
ProjectA	0.06	0.06	0.3	**0.0912**
ProjectB	0.87	0.93	0.53	**0.86**
ProjectC	0.07	0.01	0.16	**0.0475**

Calculated weight vectors were used in Table 4.16. Weight vector for resources; $W_R = (0.78, 0, 0.22)^T$, weight vectors for capital, time and labor were calculated before.

$W_{cost} = (0.04, 0.96, 0.0)^T$

$W_{time} = (0.13, 0.57, 0.30)^T$

$W_{labor} = (0.13, 0.57, 0.30)^T$

After placing these values into the table priority weights of projects were calculated considering the main criteria. Then general priority weights for projects were calculated as follows:

Priority weight for Project A = [(0.3x0.06) + (0.57x0.06) + (0.13x0.3)] = 0.0912

Priority weight for Project B = [(0.3x0.87) + (0.57x0.93) + (0.13x0.53)] = **0.86**

Priority weight for Project C = [(0.3x0.07) + (0.57x0.01) + (0.13x0.16)] = 0.0475

With respect to the results, Project B "Optimization of Material Transferring Heat Loss" was selected as a Six Sigma Project for 2009.

CHAPTER FIVE
SIX SIGMA APPLICATION

5.1 Introduction

In this chapter an application of Six Sigma Methodology in an automotive supplier firm will be explained. It is explained in detail how various techniques and tools within Six Sigma methodology is applied in Section 5.2.

Project is realized in Hayes-Lemmerz İnci Aluminum Wheel Factory. Hayes Lemmerz International, Inc. was originally founded in 1908 and is the world's largest producer of automotive and commercial highway steel and aluminum wheels.

5.2 Project Application

5.2.1 Project Definition

After project selection “Energy Cost Reduction by Optimization of Material Transferring Heat Loss” project is decided for implementation.

It is aimed that electricity and natural gas consumption will decrease by realizing this project. Water consumption is not included in the project. Project encloses from melting area to Casting Area (until melted alloy is loaded to casting machine).

Figure 5.1 General view of melting area

5.2.2. Targets:

Targets of the project can be seen in Table 5.1.

Table 5.1 Targets of the project

Measure of Values	Initial	Target
Electricity Consumption (kWh/kg)	Melting : 0.003 kWh/kg Casting Heater : 0.10 kWh/kg	Melting : 0.0028 kWh/kg Casting Heater : 0.097 kWh/kg
Natural Gas Consumption (sm3/kg)	0.11 m3/kg	0.105 (%4)

5.2.3. Process Details:

Aluminum Wheel production can be analyzed in 4 phases: Melting – Casting – Machining and Painting.

Melting: Two different alloy types are used as raw material in production: Silisium 11 and Silisium 7. Every model is casted with using these two alloy types. Aluminum bullions are loaded into Melting ovens and melting process begins. Melting ovens make production according to their set values that are related to alloy type. (AlSi7 : 760C , AlSi11 : 740C) Alloy temperature is adjusted according to this value. Periodically melted alloy is taken by melting pot and taken to the Degassing section (Figure 5.2).

Figure 5.2 Melting pot

Helium is applied into molten aluminum in Gas Elimination Station. This provides a more homogenized liquid and prevents possible defects like holes and spaces that can occur during casting. The pots are heated in Pot Heating Stations during the time they spent as idle. Following the Gas Elimination process, molten metal is sent to Casting Benches in a proper order.

500 kg of metal can be collected at the Transfer Owens of the Casting Benches. Capacity of the Pots is approximately 800 kg. It is important to avoid decrease of the metal level in Casting Owens which can cause in defects and a bad quality during

Casting. In order to keep metal level at certain limits, target is to pour metal into benches on an often base. One Pot can send metal to 2 or 3 Casting Benches at once.

Casting: There are 18 Casting Benches on the shop floor. Every model that is assigned to the bench has its own special set of values indicating the Metal temperature which provides the optimum temperature for casting. In order to maintain this temperature, Casting Owens are heated regularly powered by electricity. Boiler (brulor) is triggered by the decrease in temperature and starts heating Owen. Due to this set-up, temperature of the metal that is being poured is vital. This process is critical for controlling the electricity use and waste regarding the start of the boilers activity with the new molten metal with a lower temperature. If the temperature of the metal is lower than the set value, boilers will start and this will cause unnecessary use of electrical power. If the temperature is higher than the set value, then it is recognized that there has been a waste of energy during Molding.

This project aims to minimize the unnecessary use (waste) and optimize the use of electricity and natural gas by analyzing and focusing on the Transfer Process and Molding Process.

Table 5.2 Samples for set temperatures according to models

Model	Alloy Temperature	Tolerance	Alloy
1653	700	±*10*	AlSi11
1473	690	±*10*	AlSi11
1731	680	±*10*	AlSi11
1752	680	±*15*	AlSi11
4364/1	710	±*10*	AlSi7
1754	690	±*10*	AlSi11
4267	690	±*10*	AlSi11
4259	710	±*10*	AlSi7
4260	710	±*10*	AlSi7
4370	720	±*10*	AlSi7
4448	715	±*10*	AlSi7
4464	700	±*10*	AlSi7
4281	710	±*10*	AlSi7
4280	710	±*10*	AlSi7
4447	715	±*10*	AlSi7
4379	715	±*10*	AlSi7

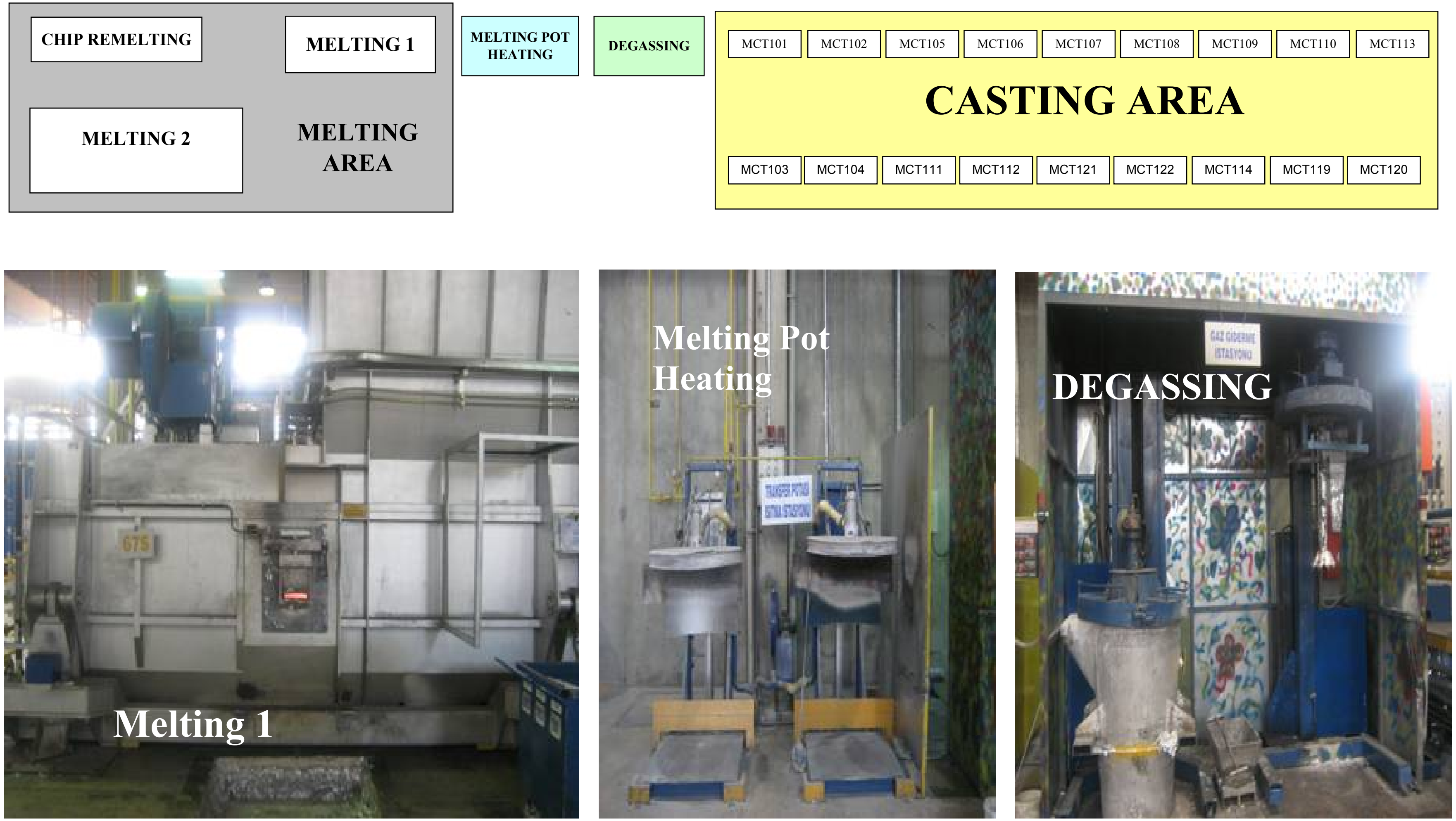

Figure 5.3 Basic layout for melting and casting area and pictures for melting, degassing and melting heat pot

5.2.4. Financial Gain of the Project

Some measurements were done to find the natural gas and electricity consumptions per kg in the areas of melting and casting. We determined the consumptions of electricity and natural gas during various shifts in the melting area. In the meantime alloy amounts were written down to the data gathering forms.

Equally electricity consumptions and alloy amounts were written down to the forms for casting machines. Consequently electricity and natural gas consumptions per kg were determined at the beginning of the project.

Electricity = 0.003 KWH/kg (for Melting)
= 0.10 KWH/kg (for Casting Machine)
Natural Gas = 0.11 Sm3/kg

We are expecting %3 improvement in electricity consumption:

Gain from Electricity = (Gain from Melting Area) + (Gain from Casting Heaters)

= [(KWH/kg in Melting * Annual Production Quantity * Wheel Weight * Electricity Price) + (KWH/kg in Casting * Annual Production Quantity * Wheel Weight * Electricity Price)] * 0.03

Gain from Electricity = [(0.003 KWH/kg * 1,320,000 wheels * 15 kg/wheels * 0.065 €) + (0.10 KWH/kg * 1,320,000 wheels * 15 kg/wheels * 0.065 €)] *0.03 = **3,983 €**

We are expecting %4 improvement in natural gas consumption:

Gain from Natural Gas = (sm3/kg in Melting * Annual Production Quantity * Wheel Weight * Natural Gas Price) * 0.04

= (0.11 sm3/kg * 1,320,000 wheels * 15 kg/wheels * 0.253 €) * 0.04

= **22,007 €**

Total Gain of the Project = 3,983 € + 22,007 € = 25.990 €

5.2.5. DMAIC Cycle

5.2.5.1. Define Phase

The aim of this phase is to define the scope and goals of the project. While clarifying the goals, requirements of the customer must be considered. Project charter is used as a main tool for define phase. Project scope, boundaries, and limitations, financial gains are expressed in Project charter.

Firstly it is important to determine CTQs of the Project. CTQ factors are the important measurable characteristics of products or processes for which performance standards or specification limits must be satisfied (Eckes, 2001). A Tree Diagram was developed with team members so parameters that would be monitored were modified. In this study there were two CTQs: natural gas consumption and electricity consumption. (Figure 5.4)

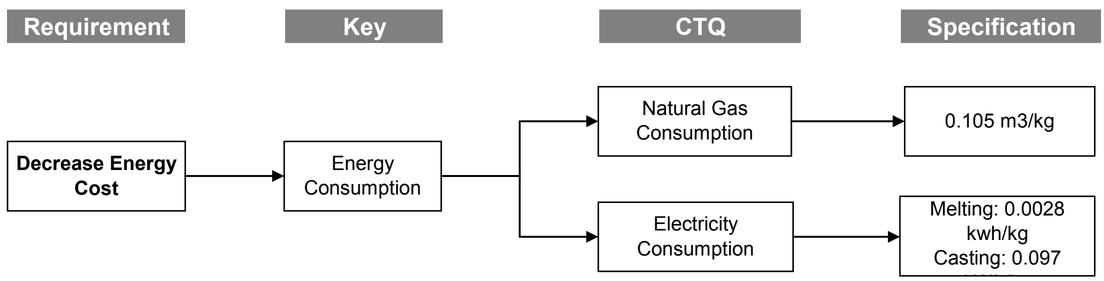

Figure 5.4 Tree diagram

Using tree diagram wider Aspect of the target was splitted into more detailed levels. CTQs of the project were determined with tree diagram and these would be used as “Output” in the S.I.P.O.C.

S.I.P.O.C. diagram is a tool that helps project team to see all elements of the process. It is a macro level process map. S.I.P.O.C. diagram is given in Figure 5.5.

Supplier	Input	Proccess	Output	Customer
DUBAL DUBAI ALUMINIUM	PRIMARY INGOT	Material Melting and Transferring	Electricity Consumption	Casting
FACTORY	SECONDARY INGOT		Natural Gas Consumption	Management
FACTORY	SCRAP			
FACTORY	CHIP			
MOSB	Electricity			
MOSB	Natural Gas			
ALTEK	Magnesium			
	Strontium			
ASTURIANA DE ALEACIONES	Ti-Bor			
	Virgin Aluminum/ Master20			
İK	Operator			
	Pot			
	Work Instructions			
	Equipment			
	Forklift			

Figure 5.5 S.I.P.O.C. diagram

Detailed Process Map was developed with team members after completing S.I.P.O.C. Generally detailed process map is consists of 1+7 steps.

Step 0: Supplier list and customer expectations will be specified

Step 1: Define important **outputs** considering general **inputs** and customer expectations

Step 2: Define process steps

Step 3: Define steps that have no impact on the output quality (non-added value steps).

Step 4: Define basic outputs for every process step

Step 5: Define basic inputs for every process step

Step 6: Categorize basic inputs for every process step

Step 7: Define controllable specifications for basic inputs

Figure 5.6 shows the detailed process map. Process outputs and basic inputs were defined and categorized with team members. Three categories are used for categorizing:

Noise Inputs: They have effects on outputs but it is not easy or possible to control these variables (Ambient temperature, humidity…etc.).

Process Parameters: These have effects on outputs (Pressure, temperature…etc.).

Procedures: Standard procedures. (E.g. work instructions)

Basic inputs are used in Prioritization Matrix to establish relations with process outputs. Prioritization for CTQs is done and relations between CTQs and process inputs are graded. Determining which process inputs will be focal point to meet the requirements of CTQs is the important result of Prioritization Matrix. Thus which process input has effect on which process output is identified.

In this study CTQs were graded in the scale of 1-10 related to customer prioritization. Scoring was done according to this scale:

0 = no relationship

1 = very weak relationship

3 = medium level relationship

5 = strong relationship

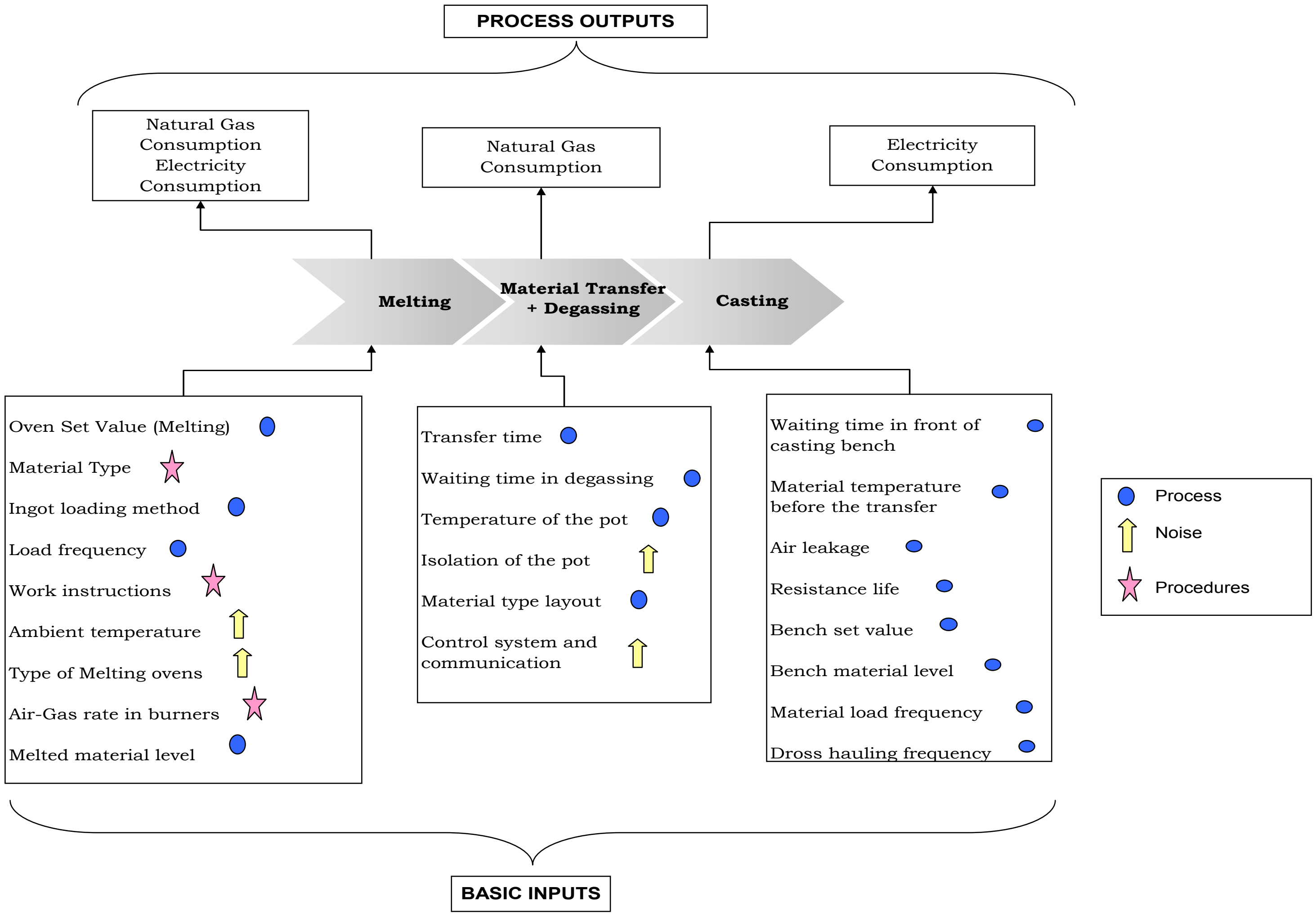

Figure 5.6 Detailed process map

9 = Very strong relationship

Table 5.3 shows Prioritization Matrix.

Table 5.3 Prioritization matrix

Prioritization Matrice			Natural Gas Consumption	Electricity Consumption	
		OUTPUTS	10	8	Degree of Importance
Nr	Process Step	INPUTS	77	138	TOTAL
1	MELTING	Oven Set Value (Melting)	9	3	204
2	MELTING	Material Type	1	1	28
3	MELTING	Ingot Loading Method	3	2	46
4	MELTING	Load Frequency	9	3	114
5	MELTING	Work Instructions	5	3	104
6	MELTING	Ambient Temperature	1	1	68
7	MELTING	Type of Melting Ovens	3	1	48
8	MELTING	Melted Material Level	5	3	74
9	MELTING	Air-Gas Rate in Burners	7	1	108
10	MET. TR-DEG	Temperature of the Pot	8	9	152
11	MET. TR-DEG	Isolation of the Pot	8	8	144
12	MET. TR-DEG	Material Type Layout	7	8	134
13	MET. TR-DEG	Control System and Communication	1	8	74
14	MET. TR-DEG	Transfer Time	1	9	235
15	MET. TR-DEG	Waiting Time in Degassing	1	8	317
16	CASTING	Waiting Time in front of Casting Bench	1	9	325
17	CASTING	Material Temperature before the Transfer	1	9	262
18	CASTING	Air Leakage	1	9	82
19	CASTING	Resistance Life	1	8	74
20	CASTING	Bench Set Value	1	9	82
21	CASTING	Bench Material Level	1	9	82
22	CASTING	Material Load Frequency	1	9	82
23	CASTING	Dross Hauling Frequency	1	8	74

Inputs that have big impact on natural gas and electricity consumption were identified:

1) Waiting time in front of casting bench
2) Waiting time in degassing

3) Transfer time
4) Oven Set Value (Melting)
5) Temperature of the Pot
6) Isolation of the pot

By developing prioritization matrix project team had important inputs and define phase was completed.

5.2.5.2 Measure Phase

By define phase it was determined that which data would be collected. So data gathering plan and data collecting forms would be composed (Table 5.4). Project team continued to data collection for two months and gathered 50 samples. While collecting data it was a chance to analyze process steps and discover the non-value added works.

Table 5.4 a sample for data collection form

DATA COLLECTION FORM FOR MATERIAL TRANSFER

DATE : **OPERATION :** **OPERATOR:**
SHIFT :

MELTING OVEN : **MELTING OVEN SET TEMPERATURE:** **POT NO** **LEVEL OF MATERIAL:** EMPTY HALF LOADED
MATERIAL TYPE :

ÜRETİM						MAINTENANCE			
NR	DURATION	ACTIVITIES	MATERIAL TEMPERATURE	CASTING BENCH NO	SET VALUE	Flow	Power	Consumed Energy	Last date of resisance change
		Pot temperature before having material							
1		Transfering from melting to degassing							
2		Degassing time (operation and waiting)							
3		Dross taking							
4		Waiting time after dross taking							
5		Transfering from degassing to casting bench							
6		Waiting time in front of casting bench							
7		Filling the melted material to casting bench							

Project team collected these data:

- Durations of every work step during the material transfer process
- Material temperature in every work step
- Consumed natural gas and electricity in casting and melting area
- Set temperatures, production quantities, pot temperatures…etc.

5.2.5.3 Analyze Phase

In the analysis step, the data collected from the process is analyzed in various points. Focused points for analyze phase in this study:

- Find out non-value added steps
- Eliminate unnecessary waiting times that cause decrease in material temperature (Interval of set temperature value is 680-710°C for casting machines. If temperature of the transferred material is lower than set temperature, casting bench will try to heat material until the set value, this causes energy waste).
- Find out optimum temperature of the transferring pot

Project team used Minitab statistical software for some analysis.

5.2.5.3.1. Boxplot: Firstly durations of every step were analyzed. Figure 5.7 shows that the box-plot of every work steps durations.

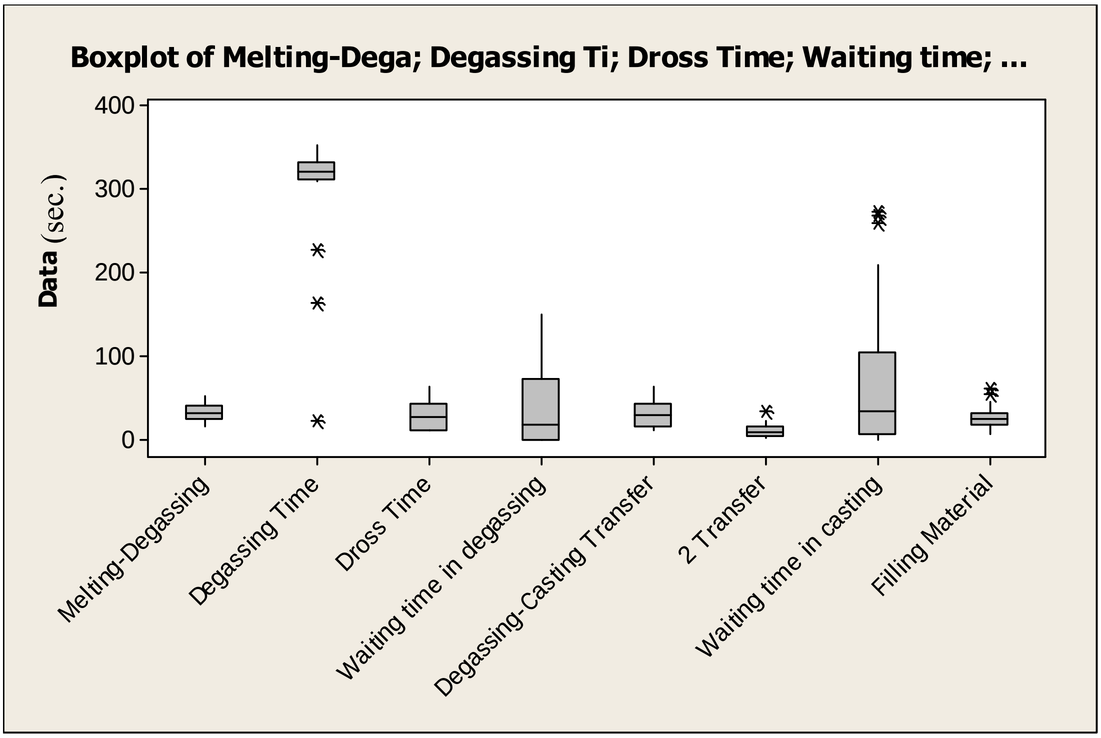

Figure 5.7 Box plot of work step durations

When the box plot was analyzed three important points were realized:

1) Degassing time was very long. Material temperature was decreasing approximately 30 degrees at the end of this step.
2) "Waiting time in degassing" was a non-value added work step. This step must have been analyzed.
3) Waiting time in casting was very long and variance was high too.

A meeting was done with production engineers about the possibility of decreasing degassing operation time. After researches it is understood that decreasing degassing time was not possible because it would cause increase in "casting hole" scraps.

Project team used fitted line plot to evaluate the amplitude of temperature decrease. An equation showed the relationship between time and temperature was shown in Figure 5.8. This means that temperature is decreasing 5 degrees in every single minute.

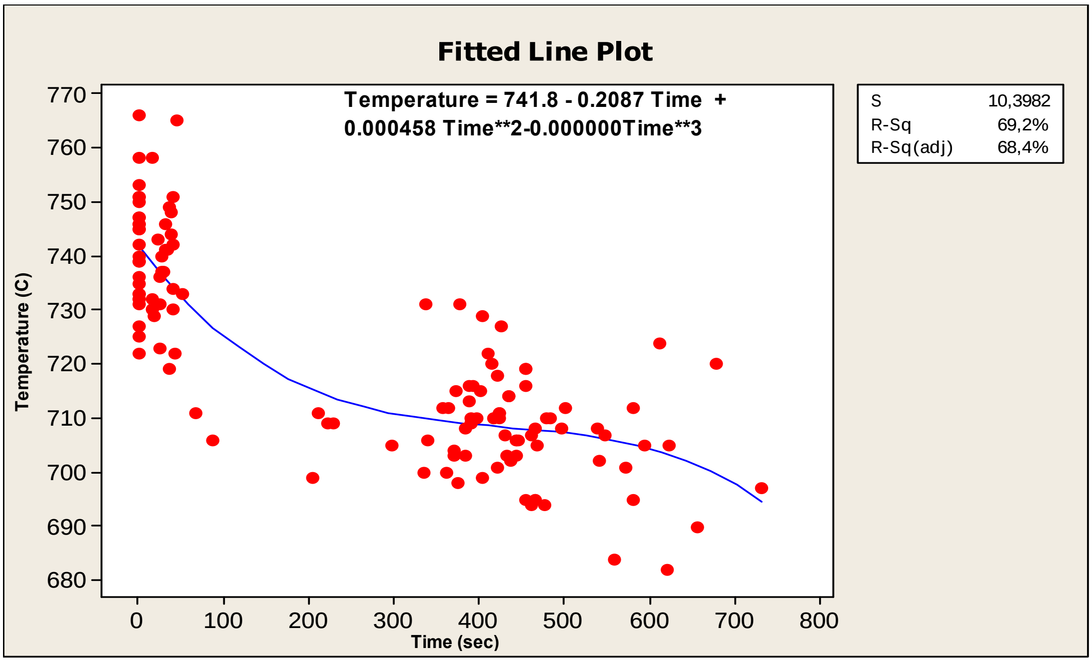

Figure 5.8 Fitted line plot

5.2.5.3.2.FMEA: In the analyze phase it is a good way to use FMEA to understand relationships between risks and process steps. FMEA helps to prioritize improvement actions. According to FMEA in Table 5.5, Project team focused on “waiting time in front of bench”. A casting bench is able to get material when its inside pressure is equal to zero. If it is not equal to zero material transfer operator must wait until the pressure equal to zero. This waiting time can be 1 second to 300 seconds and it causes temperature loss in melted material in the transfer pot.

In the current system there wasn’t any sign showed that the casting bench was ready to get material. Material transfer operators were giving melted material to casting benches in a row. If the casting bench was not ready they were waiting and these would cause energy loss. Project team decided to establish a warning system between casting bench and material transfer operators. It will be expressed in detail on “Improve Phase”.

Table 5.5 FMEA for material transfer process

Process Function Requirements	Potential Failure Mode	Potential Effects of Failure	S	Potential Causes / Mechanisms of Failure	O	Current Process Controls	D	RPN	Recommended Actions	Responsibility and Target Completion Dates
MATERIAL TRANSFER	Waiting time infront of casting bench	Temperature of material is lower than set temperature - energy loss	8	There isn't any sign that casting bench is available for material transfer	8	-	9	576	Establishing a warning system	Maintenance
	Material transfer with wrong type of material	Production loss	7	Lack of attention	2	-	3	42	Material Type Labels	Casting
	Delay in material filling in casting bench	Low quality casting Production loss	9	There isn't any indicator that shows material level	5	Operator Loading Form	3	135	Indicators that show material level	Maintenance

5.2.5.3.3.Taguchi Experimental Design: Material was transferring using transfer pots. Project team also made an analyze about Transfer pots. These pots didn’t have any isolations and cover on the top. They were heated up before transferring operations but there was not a specific temperature for pots. It was decided to collect some data about the decrease of material temperature related to pots. There were four factors about transfer pots:

1) Pot Temperature (130 – 320 - 570)
2) Isolation Status (isolated – non isolated)

3) Production Status (on production – empty)
4) Pot Cover Status (with cover – no cover)

Pot Temperature: Three temperature levels were chosen. (130, 320, 570)

Isolation Status: Measurements were done with both isolated and non-isolated pots to see if isolation status had an effect on temperature decrease.

Production Status: On production or empty.

Pot cover status: A sample pot with cover was designed and used for measurements.

Using DOE method number of experiments was eliminated. There were 24 different combinations to use all levels of factors.

$2^3 * 3^1 = 24$ (Three factors with two levels, one factor with three levels)

Taguchi orthogonal arrays were used to decide experiments. L9 Standards Array was proper for this case (Table 5.6). For every experiment four measurements were done.

Table 5.6 L9 array for transfer pot measurements

Pot Temperature	Isolation Status	Production Status	Pot Cover Status	ΔT1	ΔT2	ΔT3	ΔT4
130	Isolated	On production	With cover	72	72	70	74
130	Non-isolated	Empty	No cover	80	85	79	102
130	Isolated	On production	With cover	70	70	71	69
320	Isolated	Empty	With cover	40	40	41	40
320	Non-isolated	On production	With cover	59	61	58	67
320	Isolated	On production	No cover	45	46	46	47
570	Isolated	On production	No cover	28	28	28	27
570	Non-isolated	On production	With cover	31	31	31	32
570	Isolated	Empty	With cover	27	26	27	27

Pots were heated up to three different temperatures (130, 320, 570). After heating pots were filled up with material (beginning temperature was 740 for material). During 20 minutes project team collected the decrease of material temperature data (ΔT). Using equation 3.2 to 3.4 S/N ratios and means were obtained. Table 5.7 showed S/N ratios and means.

Table 5.7 S/N ratios and means

ΔT1	**ΔT2**	**ΔT3**	**ΔT4**	**σ**	**Mean**	**S/N**
72	72	70	74	1.632993	72	32.887
80	85	79	102	10.66146	86.5	18.184
70	70	71	69	0.816497	70	38.663
40	40	41	40	0.5	40.25	38.116
59	61	58	67	4.031129	61.25	23.634
45	46	46	47	0.816497	46	35.016
28	28	28	27	0.5	27.75	34.886
31	31	31	32	0.5	31.25	35.918
27	26	27	27	0.5	26.75	34.567

For example S/N ratio of first row:

$$S/N = \eta = 10 \times \log\left[\frac{\bar{y}^2}{\sigma^2}\right] = 10 \text{ x } \log[(72)^2/(1.63)^2] = 32.887$$

After these calculations output tables for S/N and Means were composed using the equations 3.5 to 3.7. Output Tables for S/N ratios and Means can be seen in the tables 5.8 and 5.9.

Table 5.8 Output table for S/N

Output Table for S/N				
Level	**A**	**B**	**C**	**D**
1	29.911	35.296	34.607	30.363
2	32.255	25.912	30.289	29.362
3	35.124	36.082	32.394	37.565
Δ	5.2122	10.17	4.3179	8.2035

As an example:

Value of B for Level 1 = B_1 = $(S/N_1+S/N_4+S/N_7)/3$

= (32.887+38.116+34.886)/3 = 35.296

Value of A for Level 2 = A_2 = $(S/N_4+S/N_5+S/N_6)/3$

$= (38.116+23.633+35.016)/3 = 32.255$

Table 5.9 Output table for means

Output Table for Means				
Level	**A**	**B**	**C**	**D**
1	76.167	46.667	49.75	53.333
2	49.167	59.667	51.167	53.417
3	28.583	47.583	53	47.167
Δ	47.583	13	3.25	6.25

Three factors were decided according to the graph of SN ratios in Figure 5.9. SN ratios with the highest level were chosen for optimum combination.

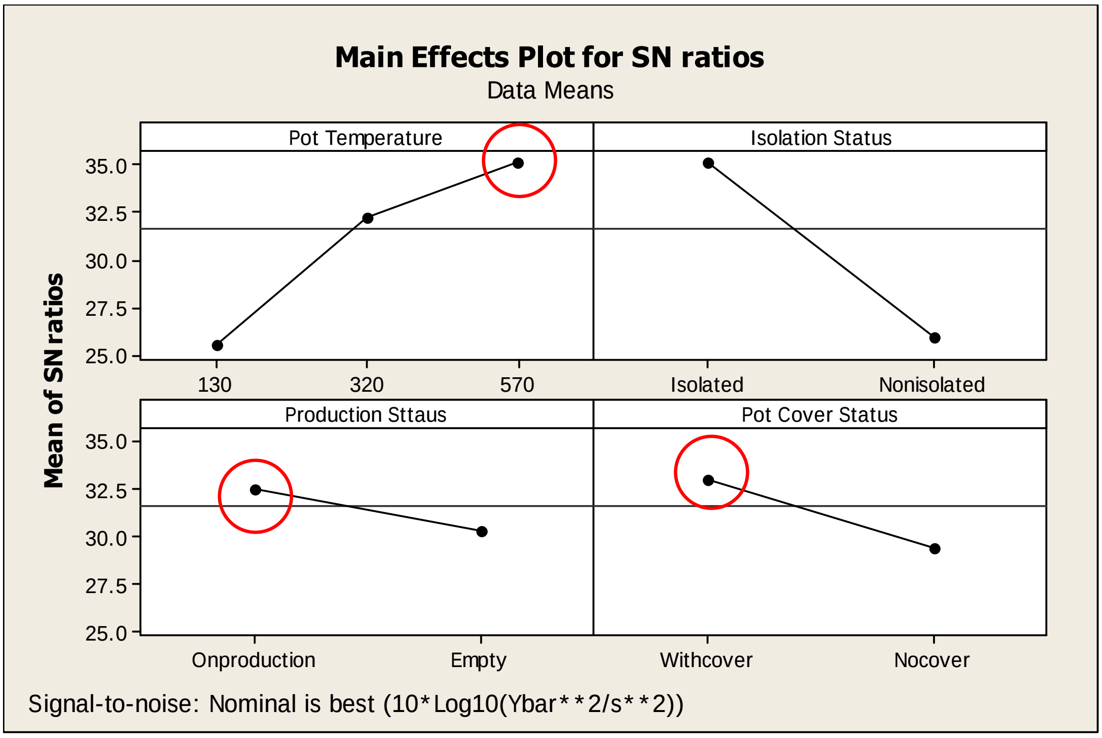

Figure 5.9 Main effects plot for SN ratios

Optimum values for factors:

Pot temperature: 570 degree

Production Status: On production

Pot Cover Status: With Cover

Isolation status factor was decided according to the graph of Means in Figure 5.10. For isolated pots it can be seen that ΔT is lower.

Isolation Status: Isolated

Values of these four factors were determined for optimum solution.

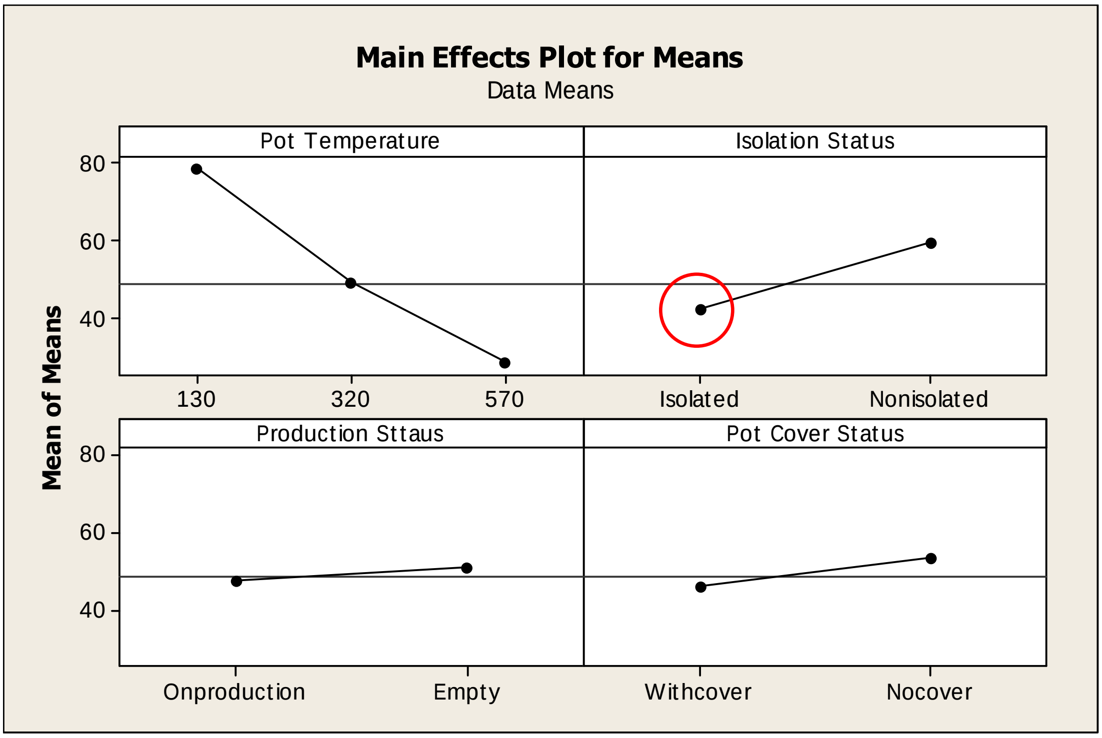

Figure 5.10 Main effects plot for means

5.2.5.3.4. Scatterplot: Change in material temperature versus time can be seen in Figure 5.11. In twenty minutes it was understood that pots that were heated up to 570 degree before the beginning of material transfer showed least heat loss (around 30 degrees).

Generally casting set temperatures differ from 680 to 710 degree. Material is taken from Melting Ovens at 760 or 740 degree. The objective is support material to casting ovens in the range of 680 – 710 degree.

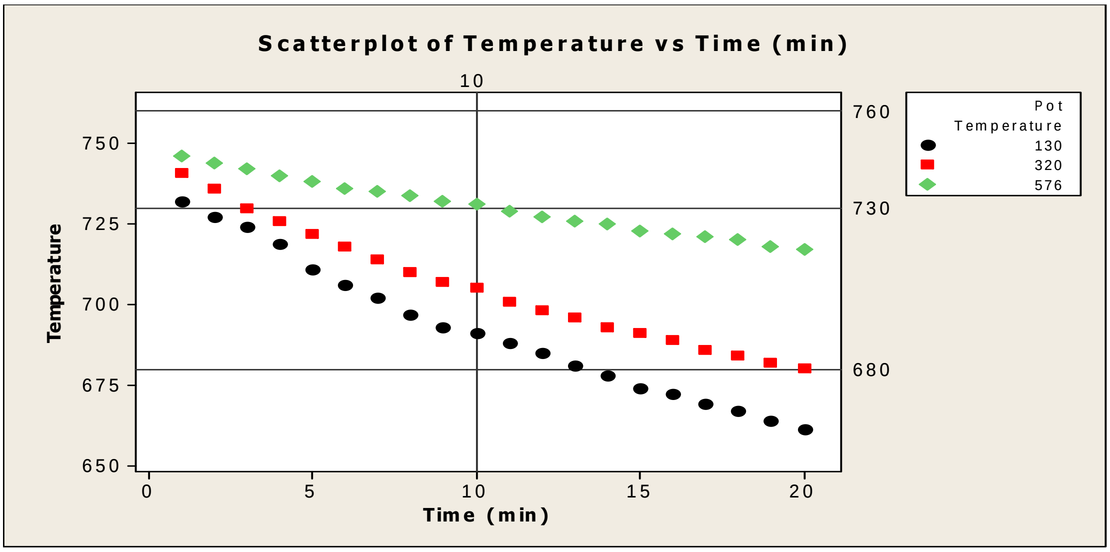

Figure 5.11 Scatter plot of material temperature versus time

5.2.5.4 Improve Phase

Following the analysis phase, improvement studies began to determine the actions to be taken to eliminate current problems. The focus of this section is on the possible improvement proposals that were structured in the light of findings from Analysis Phase.

Degassing Time: Findings from Analysis Phase show that the longer operation time causes need of longer time for decrease of metal temperature. Attempts with less Degassing time points out a negative result regarding the loss of casting quality and observed defects of Holes in Casting. For this reason, no changes were made to Degassing time.

Waiting time after Degassing: It was understood that operations after Degassing station was undefined and non-value added actions. After observation of this fact, meetings were held with the operators and waiting time was eliminated in most case and minimized for the rest.

Waiting before Casting Bench: This problem had the biggest role in loss of metal temperature during transfers. Metal was fed to the Casting Benches by the operators without knowing the availability of the Bench and this was causing a waiting period of up to 4-5 minutes. In order to clear the availability situation, an informative system was designed.

In order metal to be fed to the Casting Bench, previous Casting cycle has to be completed and pressure inside the Oven has to be zero. But as the operators didn’t know the point of process in this cycle, they were starting the feed and some this was resulting in unwanted standbys. To clarify the availability of the Ovens, lights were implemented to the Ovens which were set-up to show Green when the pressure inside decreases to 0. So whenever an operator arrives to the Casting Benches, he was able to understand the available Bench to start the feeding. After revising the related Procedures and short trainings to the operators, this process has become a standard (Figure 5.12).

Figure 5.12 Green lights on casting benches

Besides Availability Lights, a three degree lightning system was also set-up to show the metal level inside the bench in order to let the operator to know amount of metal to inside. After this implementation, operator was able to know which Bench to choose according to availability, how much and in what sequence he should start feeding metal to the possible selections regarding the amount of metal in the Bench (i.e. start feeding the bench which has the lowest level of metal).

3 degree was represented by different colors:

Green Light: Metal Level is sufficient

Yellow Light: Available to be fed

Red Light: Metal Level is very low

Figure 5.13 Three degree lightening system showing level of metal inside bench

After the above improvements, measurement and time studies were repeated. Based on new data, Hypothesis Test was used to understand the difference between previous and new statuses if there was any. Considering the average values were going to be compared, “t test” was selected as the appropriate method. First check point was the variances. As seen on Figure 5.14, the variances between new states are different from each other.

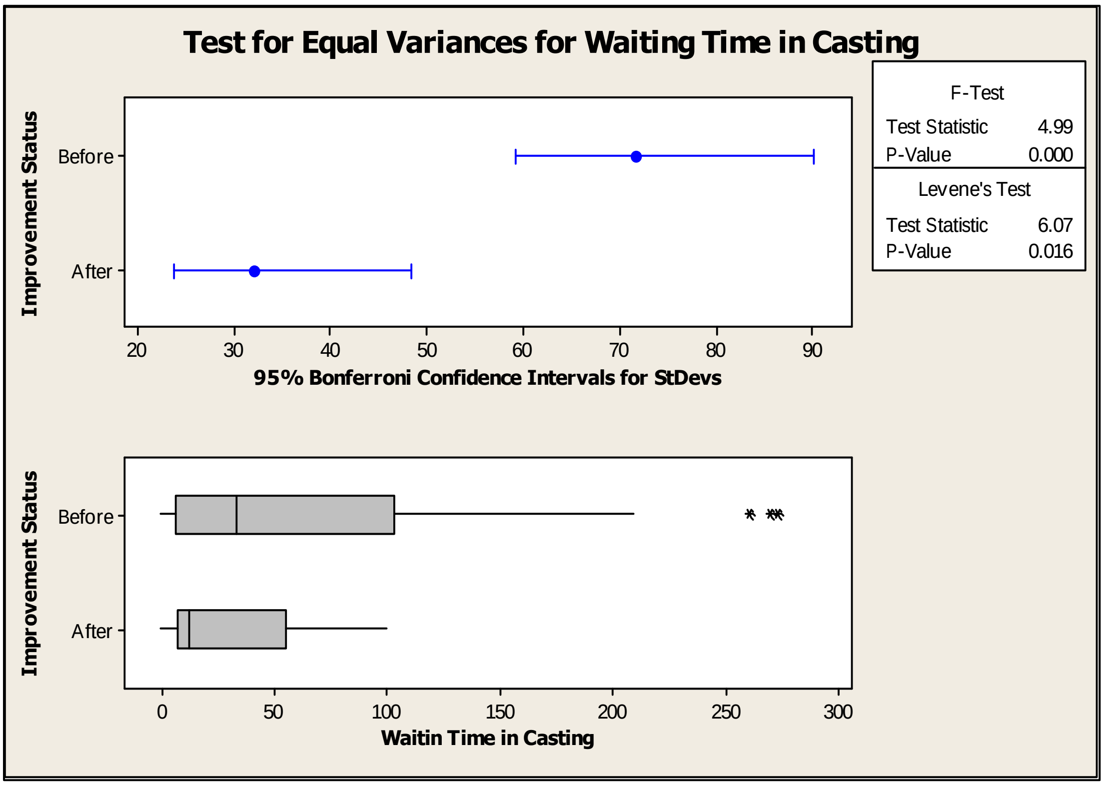

Figure 5.14 Test of variances

According to the results of t test, average waiting time in casting has changed before and after the improvements.

H_0: µA= µB (Avg. waiting time before improvement and after improvement avg. waiting time is equal)

Ha: µA≠ µB

α =0,05

Figure 5.15 shows the Minitab test result of two sample t-test.

Two-Sample T-Test and CI: S Waiting Time in Casting - Before; S Waiting Time in Casting - After

```
Two-sample T for S Ocak Önü Bekleme-Önce vs S Ocak Önü Bekleme-Sonra

                                   N  Mean   StDev  SE Mean
S Waiting Time in Casting-Before   59  61,3   71,5      9,3
S Waiting Time in Casting-After    22  27,0   32,0      6,8


Difference = mu (S Waiting Time in Casting-Before) - mu (S Waiting Time in Casting-After)
Estimate for difference:  34,3
95% CI for difference:  (11,3; 57,3)
T-Test of difference = 0 (vs not =): T-Value = 2,97  P-Value = 0,004  DF = 76
```

Figure 5.15 Result of t-test

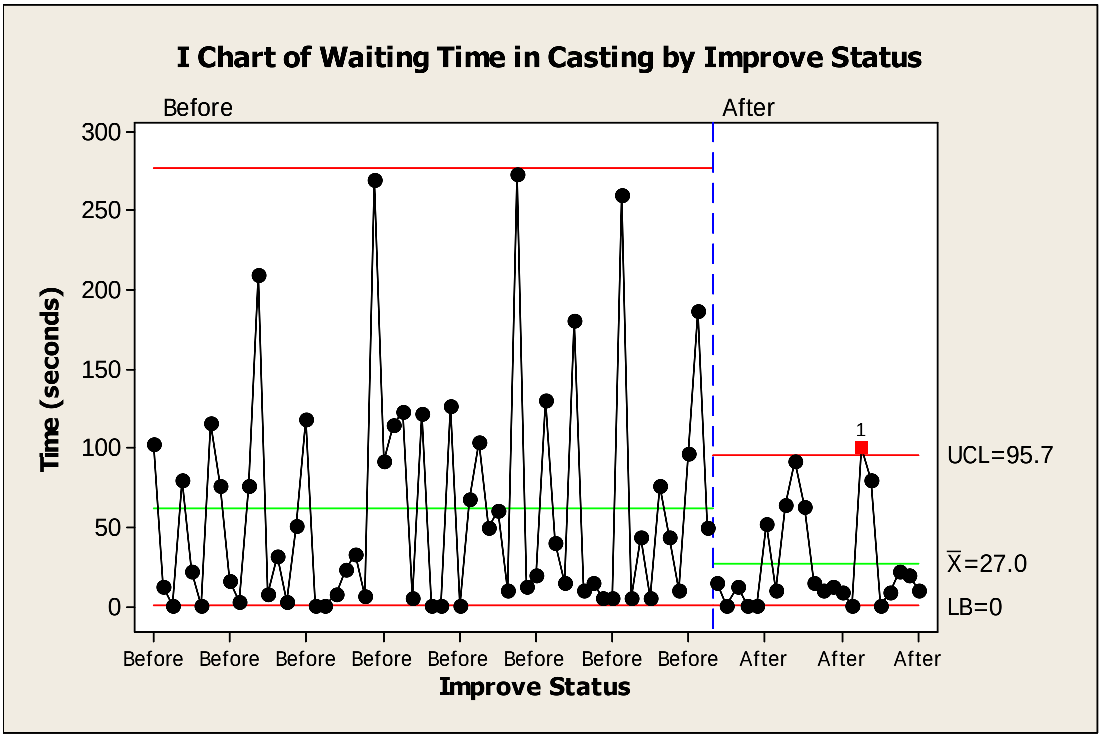

Figure 5.16 I-Chart for waiting time in casting by improvement status

Before-After Analysis is used to calculate the ratio of the improvement level. Results of this analysis show not only the decrease in average value but also in the variance figure. Average of waiting time in casting was decreased from 62 seconds to 27 after the improvements (Figure 5.16).

Improvements of Transfer Pots: As a result of the Taguchi Orthogonal Arrays study it was decided to standardize all transfer pots.

All transfer pots were isolated. Proposal was collected from supplier to design a cover on the top of pots (Figure 5.17).

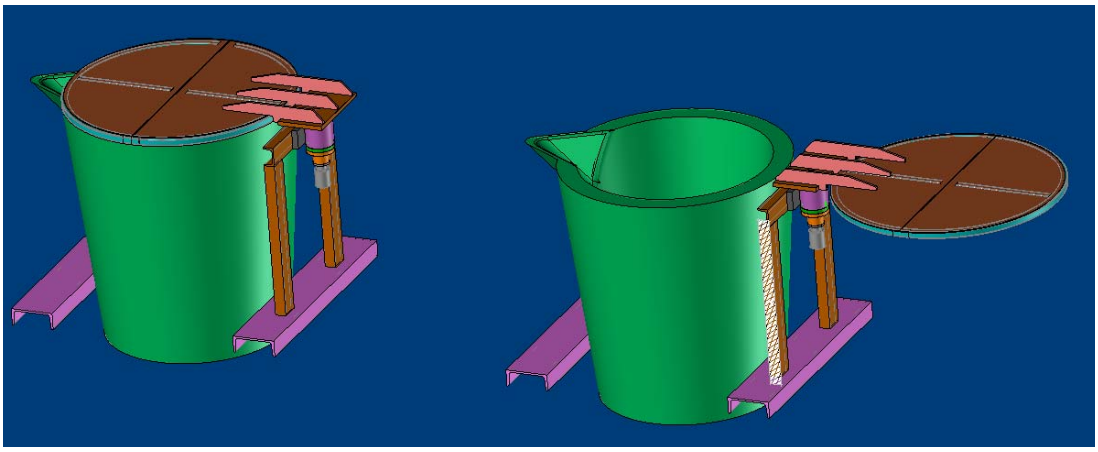

Figure 5.17 New designs for cover on the top of pots

As a standard it was decided to heat up transfer pots to 570 degree.

Other things to do: Slope difference between melting and degassing was causing time loss while transferring metal with forklift. Forklifts had to slow down while passing over this area not to overflow material to the outside. There was a risk for job security also. When the required resource will be provided it is planned to remove this slope (Figure 5.18).

Figure 5.18 Slope difference between melting and degassing

5.2.5.5 Control Phase

In this phase project team ensures that the processes continue to work well, produce desired output results, and preserve quality levels.

Three monitored parameter in the project:

1. Natural gas consumption in Melting Ovens (Target: 0.105 kWh/kg)
2. Electricity consumption in Casting Benches (Target: 0.097 kWh/kg)
3. Electricity consumption in Melting Ovens (Target: 0.0028 kWh/kg)

After improvement actions, measurements continued periodically. Project team evaluated the results by using I-Charts. After improvements Natural Gas consumption value decreased to 0.10079 sm3/kg (Figure 5.19).

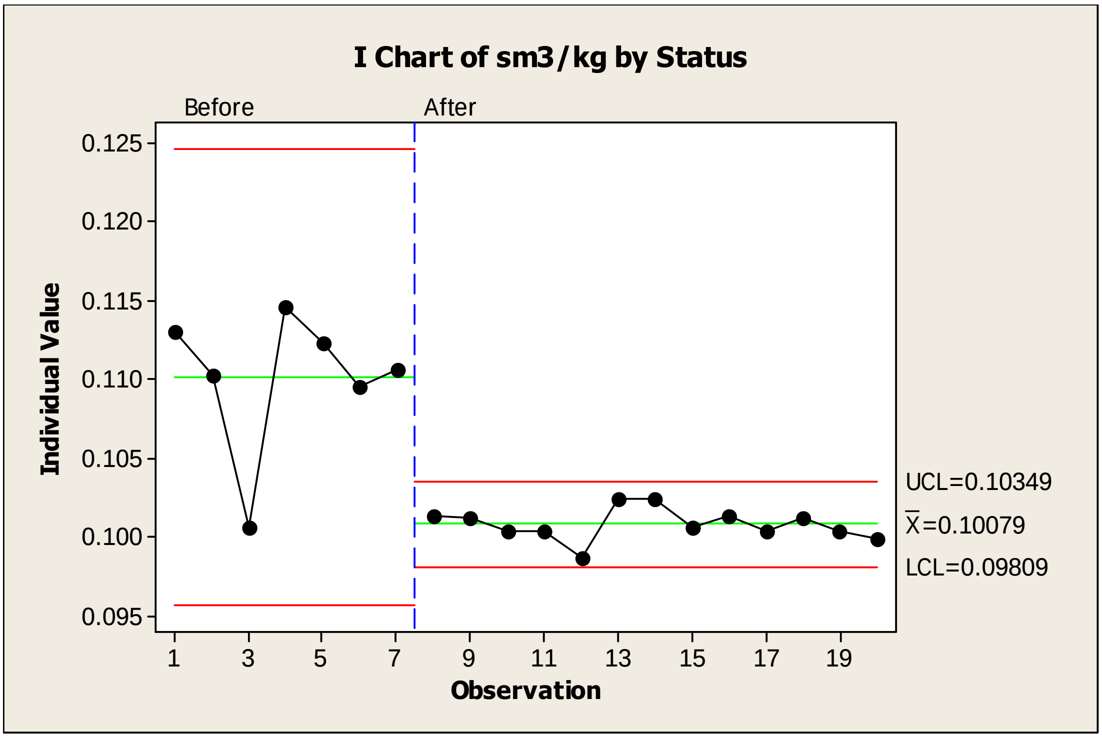

Figure 5.19 I-Chart of natural gas consumption in melting ovens

Electricity consumption in casting benches fell down from 0.100 kWh/kg to 0.08976 kWh/kg (Figure 5.20).

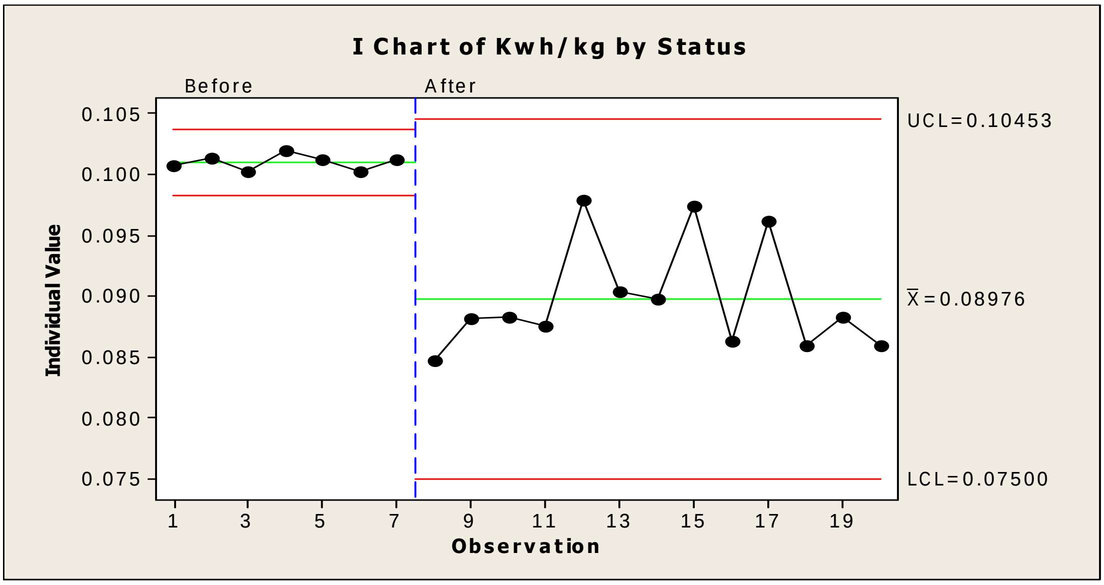

Figure 5.20 I-Chart of electricity consumption in casting benches

Figure 5.21 shows that new average value of electricity consumption in melting ovens is 0.002789 kWh/kg.

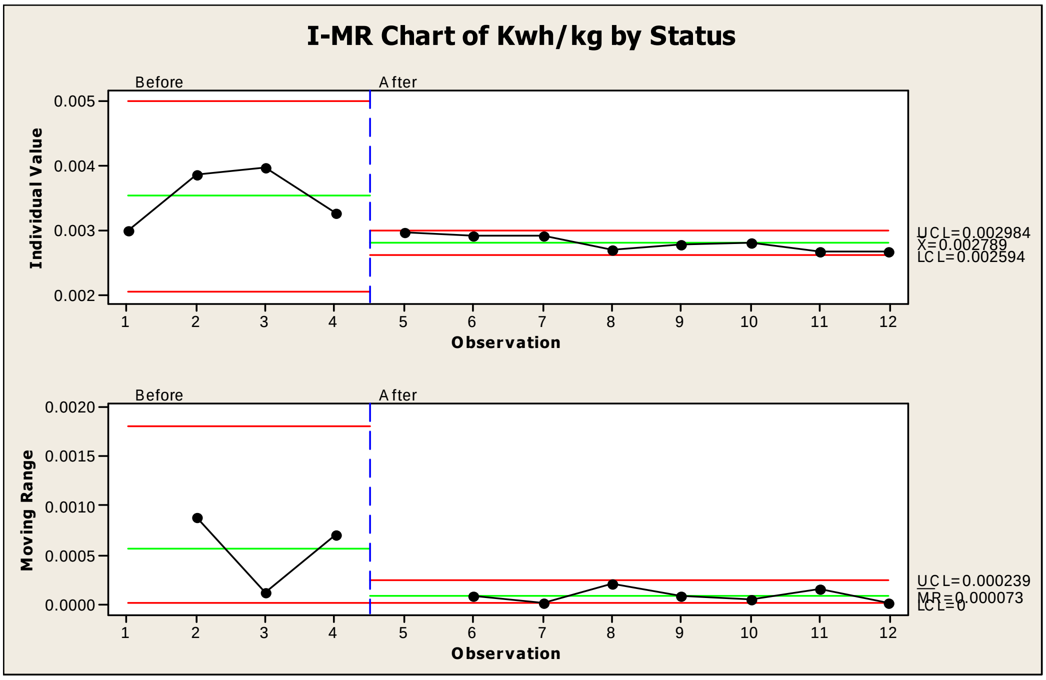

Figure 5.21 I-MR Chart of electricity consumption in melting ovens

As a summary table 5.10 shows the target and realized values of project criteria.

Table 5.10 Final situations of the project criteria

Criteria	Initial	Realized	Target
Natural Gas Consumption (sm3/kg)	0.11 m3/kg	0.101 m3/kg	0.105 (%4)
Electricity Consumption (kWh/kg)	Melting : 0.003 kWh/kg Casting Heater : 0.10 kWh/kg	Melting : 0.0027 kWh/kg Casting Heater : 0.089 kWh/kg	Melting : 0.0028 kWh/kg Casting Heater : 0.097 kWh/kg

In the control phase another important point is standardization. Standardization makes sure that important elements of a process are performed consistently in the most effective manner. After improvement actions, required procedures were prepared for material transfer operation according to new conditions.

CHAPTER SIX
CONCLUSION

In this concluding chapter, what has been accomplished in this thesis will be summarized and we mention some topics that can be addressed as a future work.

Six Sigma is a systematic methodology that utilizes information and statistical analysis to measure and improve a company's operational performance and systems by identifying and preventing 'defects' in manufacturing and service-related processes in order to exceed expectations of customers.

Six Sigma is a quality management philosophy which sets very high standards for itself. Its program predicts that increase in number of sigma will decrease the differences from set targets –in other words amount of turnover rates-. In this approach, product and service performance of the company is measured by sigma level. Sigma level will continue to increase as the company determines and corrects the reasons which cause the deviations in business processes. This progress means decrease in number of errors and failures in business and production processes. The main target of Six Sigma is reaching products and processes which perfectly satisfy requirements and expectations, minimizing variation and deviation to zero.

The main identifiers and supreme features of Six Sigma amongst other improvement techniques are; its rich ground which covers many customer oriented and problem solving techniques and its scientific methodology which is based on statistics.

In this study a brief knowledge about the nature of Six Sigma and objectives are mentioned. Furthermore project selection that features in achieving success is also given. A detailed literature review of Six Sigma and Six Sigma project selection applications is provided. DMAIC Six Sigma methodology and its tools are studied.

In chapter four using Fuzzy AHP method Six Sigma project selection problem is discussed. It is concluded in chapter four using fuzzy set theory helps us to deal with the vagueness while evaluation of data. Because of the fact that the judgments of humans are corresponded by linguistic and indefinite patterns, good decision making models should be able to tolerate vagueness or ambiguity (Yu, 2002).

After selection of Six Sigma project, a case study is examined step by step in detail. Used qualitative or quantitative tools (Taguchi design, FMEA, Hypothesis tests, Box plot analysis) are expressed. In conclusion expected values of project criteria are reached. Expected gain was 25,990 €/year at the beginning of the project. After realizations around 29,000 € for a six month period was gained.

Six Sigma is being a popular icon of statistics and management, a trademark and being a cult all over the globe. Companies that implement Six Sigma are not only saving millions of dollars but also are having significant increases in productivity, efficiency, quality and customer satisfaction levels. Other benefits of Six Sigma are reduction in in-process defect levels, reduction in maintenance inspection time, improving capacity cycle time, improving inventory on-time delivery, increasing savings in capital expenditures, increase in profitability, reduction of operational costs, reduction in the cost of poor quality (COPQ), increase in productivity, reduction of cycle time, reduction of customer complaints, improved sales and reduced inspection (Aboelmaged M. G., 2009).

As a future research detailed analysis of Six Sigma tools that couldn't be mentioned in this study can be investigated. Six Sigma theory and how does it integrate with other improvement strategies should be a potential future work. Additionally managing Six Sigma risks and crises must be researched.

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