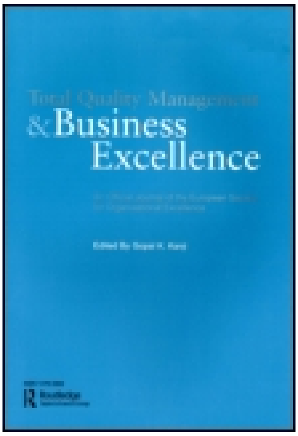

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Shell scrap reduction of foam production and lamination process in automotive industry

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Shell scrap reduction of foam production and lamination process in automotive industry

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In today's world, competition throughout industry has reached its peak. In order to survive in such a viable environment companies should perform better practices and one of the way chosen is to improve the quality of the products by reworking on its process. Therefore, in recent years, in the enhancement of manufacturing processes, Six Sigma method and its related tools are commonly utilised. Using these tools, companies reach operational excellence and attain better profit, productivity and market share. Automotive industry, on the other hand, has been the rising star in the last decade. Most of the quality-related concerns arise during the production of today's automobiles. For example, construction of the seat and the cushioning material used draws extra attention as they provide the driver and the passengers a comfortable place to sit. Today different types of foams are used in the industry. In most of the foam production processes, the chemically obtained foam needs to be laminated in order to be used in different types of seats. The manufacturing process steps of foam contain several stages that produce different levels of scrap. In this paper, a detailed application of Six Sigma methodology for reducing the shell scrap of foam production and lamination process in automotive industry is given. Throughout the paper, phases of Six Sigma, selected tools and approaches for analysis and their results are indicated in detail. Furthermore, relevant process improvement steps are also pointed out to achieve financial benefits.

Keywords: foam block production; Six Sigma methodology; automotive industry; quality; statistical tools

1. Introduction

The main initiative of lean thinking is to maximise customer value while eliminating waste. The critical objective is to offer perfect value to the customer through a perfect 'value creation' process that produces no waste. This can be accomplished through various roadmaps that are very similar to each other. Depending on the characteristics of company's culture, a suitable roadmap can be chosen and the aim of achieving 'world-class quality' can be attained (Dahlgaard & Dahlgaard-Park, 2006). The important point here is that companies should realise that none of these roadmaps work without a well-established company culture (Coronado & Antony, 2002; Dahlgaard & Dahlgaard-Park, 2006).

One of these roadmaps is the Six Sigma method. This method has its advantages over other roadmaps especially in implementation (Dahlgaard & Dahlgaard-Park, 2006). The Six Sigma method is a project-based management approach aiming to reach well-analysed targets to improve the organisation's processes, products and services by constantly

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eliminating their deficiencies (Eckes, 2003a, 2003b). Therefore, it is a business strategy that focuses on improving the understanding of the inherent production systems, productivity, customer needs and economic performance. Beginning mid-1980s, successful implementations of the Six Sigma methods allowed many organisations to keep up with their competitive advantage by incorporating their understanding of the process with statistics, engineering, and project management (Antony, Kumar, & Tiwari, 2005; ASQ, 2002; Banuelas, Antony, & Warwick, 2005; Barney & McCarty, 2002; Harry & Schroeder, 2002). Various books and articles provide the basic philosophy and benefits of the Six Sigma approach (Breyfogle, 1999; Chowdhury, 2003; Pande, Neuman, & Canavagh, 2000; Pyzdek, 2003; Slater, 1999; Yang & El-Haik, 2003). The challenges and realities in implementing the Six Sigma method effectively and profitably are enormous. Yet, the benefits of applying the Six Sigma method to technology-driven or project-driven organisations are likewise vast (Barney & McCarty, 2002; Breyfogle, 1999; Kwak & Anbari, 2006).

On the other hand, there are four key elements for a Six Sigma implementation to be successful in an organisation (Coronado & Antony, 2002; Kwak & Anbari, 2006):

(i) organisational commitment and management involvement,
(ii) project selection, management and control skills,
(iii) supporting and accepting cultural change, and
(iv) continuous education, training and dissemination.

Therefore, implementation of a successful Six Sigma project means dedication of all kinds of resources such as time, money and effort from the entire organisation. This support begins from the project selection and continues throughout the project, and it should become customary for the organisation throughout the years. There should also be a 'lessons learned' system to grasp the key issues of completed projects. If the results of Six Sigma projects are announced regularly, this will help future project teams to avoid making similar mistakes and adopt only the better practices. Furthermore, organisations that implement Six Sigma also need to continuously learn and familiarise themselves with the latest trends and techniques that are outside the Six Sigma domain that might still be useful to complement their Six Sigma way (Kwak & Anbari, 2006).

The basis of Six Sigma approach was materialised by the quality personnel (Breyfogle, 1999; Harry & Schroeder, 2002; Kwak & Anbari, 2006). From the statistical point of view, the term Six Sigma is generally defined as having less than 3.4 defects per million opportunities (DPMO) or a success rate of 99.9997% where sigma is a term used to represent the variation about the process means (Banuelas et al., 2005). This can be elaborated as follows: if an organisation is operating at, say, three-sigma level, this is interpreted as reaching a success rate of 93.32% or 66,800 DPMO (Coronado & Antony, 2002). As a result, the Six Sigma method is a very precise quality concept where many organisations today still perform at about three-sigma level.

The sigma value additionally indicates the occurrence of defects or failures; therefore, the larger sigma level indicates the less defect probability (Goh & Xie, 2003). The defects can also be defined as the dissatisfaction of the customer. Therefore, as sigma level increases, customer satisfaction also increases as cost and cycle time decreases. The task of reducing potential variability in processes and products is accomplished through define, measure, analyse, improve and control (DMAIC) cycle (Brady & Allen, 2005; McClusky, 2000). This DMAIC cycle is considered as the undersized version of the quality story which was developed in Japan but rapidly developed into an important quality improvement standard (Dahlgaard & Dahlgaard-Park, 2006). As indicated before, numerous books and articles provide the basic concepts and benefits of the Six Sigma method (Aksoy & Orbak, 2009; Hoerl, 1998, 2001). In this paper, the application of DMAIC approach is performed step by step to reduce the shell scrap percentage of foam production and lamination process in an automotive company.

This paper is organised as follows: Section 2 provides the phases of the Six Sigma project in which Section 2.1 indicates the define phase. Relevant initial state data are provided in Section 2.2, the measure phase, to identify the root causes. In this section, also supplier–input–process–output–customer (SIPOC) and critical-to-quality (CTQ) diagrams are given to illustrate the important aspects of the process and the project. Additionally, the process capability values before the initiation of the project are provided. In Section 2.3, the analysis phase is given. Section 2.4, the improvement phase, lists the improvements to the identified root causes, their validity and their results. Section 2.5, the control phase, provides the routes taken to make the improvements enduring. In Section 3, an overall evaluation of the results is given and the level of improvement is emphasised.

2. Application

In this section, the application of DMAIC approach to the shell scrap reduction of foam production and lamination process in the automotive industry is given. Fabrics inside automobiles are often composed of several layers of different materials usually a polyester fabric laminated to soft polyurethane foam. Foam is produced chemically from polyurethane as huge continuous blocks. These blocks are cut in specific heights and then transferred to another machine and laminated to desired thickness. The lamination process is chosen as the project because of increased scrap percentage, increasing customer demand, various block length and thickness types, and increasing material and operative costs. During initial discussion, the team members emphasised that the foam production process has a great impact on the lamination process. Since the lamination process is strongly affected by the foam production process, the foam production process is also added to the scope of the project.

The first step of this approach is to set forth the problem definition.

2.1. *Define phase*

This paper as explained before deals with the percentage reduction of the shell scrap of foam in the production and lamination process. This process is established in the foam production and lamination workshop of an automotive factory.

The process can be summarised as follows: in the production process, the chemical mixture is prepared beforehand and fed continuously to the vertical foam production machine. The chemical reaction produces the foam, and the foam block rises in the production machine. As the foam block rises, the vertical conveyors within the production machine help the foam block escalate. Once the height of the foam block reaches the desired value, it is cut with a horizontal blade and transferred to the settling area. After a minimum settling time of 24 h, the foam block is then taken to the cutting area for lamination.

In the lamination process, the foam block is fixed horizontally using a shaft that passes through the centre of the foam block. Then a blade is placed parallel to the foam block and laminated foam is acquired. During this process, some laminated parts of the foam block are thrown away as shell scrap until the desired laminated foam quality is achieved. This shell scrap is the one that is being dealt with in this paper.

During the define phase, the following three steps are completed by the DMAIC approach:

(1) preparation of the project charter;
(2) preparation of SIPOC diagram and process flow;
(3) determination of important inputs and outputs using cause and effect analysis.

In the preparation of project charter, the name, definition, limits and the organisation structure of the project are established. In addition, measures and related targets are defined. It should be pointed out that, potential achievements, risks, resource allocation and time schedule of the project are also identified. The project charter is a living document that should be revised as necessary throughout the schedule of the project.

The estimated target of this project is to reduce the percentage of the shell scrap from about 20% to 18%, that is, by 2%. The percentage of shell scrap before this project is observed to be approximately 20%. Therefore, a 2% decrease will provide about 10% scrap reduction. In addition to this gain, the potential achievements of this project can be listed as follows:

- operational profitability will be increased;
- production capacity will be increased;
- scrap stock area will be reduced;
- cycle time will be reduced.

It should be pointed out that the project is limited to the production and lamination of cylindrical foam blocks. Other types of foam blocks that are produced in the plant are excluded. Furthermore, there is no intervention in the chemical mixing process. Therefore, the project at hand begins with the foam block production and ends once the laminated foam is produced.

The SIPOC diagram prepared for this project by the project team can be seen in Figure 1.

The target of the reduction of shell scrap is quantified by using the CTQ diagram as seen in Figure 2. As seen in this figure, the critical measures of this project are percentage of shell scrap and volumetric value of the shell scrap.

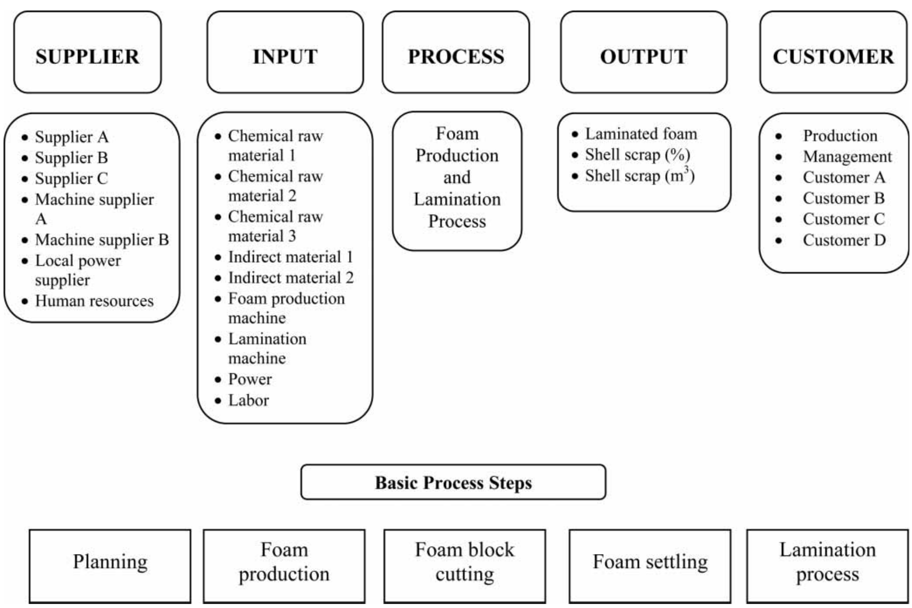

Figure 1. SIPOC diagram.

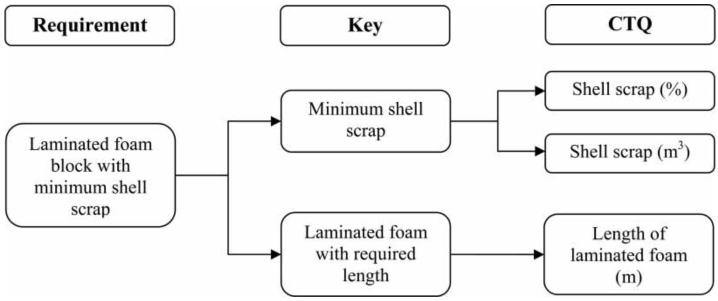

Figure 2. CTQ tree.

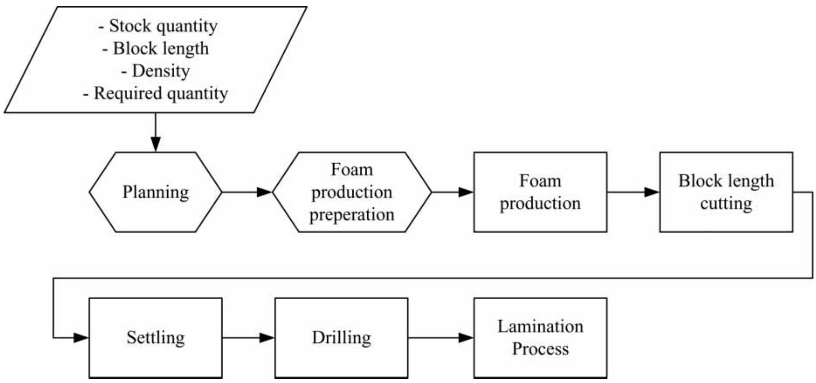

Figure 3. Detailed process flow diagram.

The detailed process flow diagram is constructed using the SIPOC diagram by the project team as seen in Figure 3. In this diagram, the important inputs and outputs of each step are presented. The important inputs and outputs can also be seen in the cause and effect matrix in Table 1. This matrix is obtained as follows:

- The importance of the output to customer is ranked between 1 and 10, 1 being the least important and 10 being the most.
- The effect of each input to each output is analysed. This is also ranked between 1 and 10, again, 1 being the least important and 10 being the most.
- The sum of products of each row provide the importance of the input to the outputs.

According to Table 1, the most important inputs are: operator experience during lamination process, setting of apparatus height during making a hole in the centre of the foam block, appropriate loading and unloading during settling process and transfer of carrier from production process to settling area. The Pareto diagram of these inputs can also be seen in Figure 4.

2.2. *Measure phase*

The aim of this phase is to indicate the actual reasons of the problems by creating the current process and problems with the conception depending on reality.

There are four steps involved in the measure phase:

Table 1. Cause and effect matrix.

			7	9	
			Outputs		
	Process Step	Priority for customer Inputs	Shell scrap	Length of laminated foam	Total
1	*Lamination*	*Operator*	9	10	**153**
2	*Drilling*	*Apparatus height adjustment*	9	9	**144**
3	*Settling*	*Appropriate loading and unloading*	9	8	**135**
4	*Settling*	*Carrier*	9	6	**117**
5	Block length cutting	Hoist holding (operator)	7	7	112
6	Drilling	Sharpness of cutting blade	5	7	98
7	Lamination	Cutting tool adjustment	5	6	89
8	Drilling	Drilling speed	5	4	71
9	Foam production	Catalyst's volumetric flow rates	3	4	57
10	Foam production	Nylon strap stiffness	3	3	48
11	Settling	Shrinkage rate	1	4	43
12	Lamination	Block length	1	3	34
13	Foam production	Conveyor speed	1	2	25
14	Block length cutting	Blade adjustment	1	2	25
15	Foam production	Raw material volumetric flow rate	1	2	25
16	Lamination	Side blade adjustment	1	1	16
17	Block length cutting	Conveyor speed (left)	1	1	16
18	Foam production	Ambient temperature	1	1	16
19	Lamination	Machine speed adjustment	1	1	16
20	Settling	Settling duration	1	1	16
		Total for outputs	74	82	

Bold values provide the numerical values of the important inputs.

(1) preparation of data collection plan;
(2) measurement system analysis (MSA);
(3) calculation of process capabilities;
(4) initial graphical analysis.

The data collection plan (Table 2) includes both outputs and the important inputs indicating the data types (quantitative or qualitative), specifications and the measurement method used.

After the preparation of the data collection plan, MSA is performed only for the lamination process operators.

In the process at hand, the decision of whether the laminated foam will be scrap is given by visual inspection. No additional analysis is done for the foam visual characteristics. After the scrapped area is removed, operators perform the visual inspection over the rest of the laminated foam and then continue through the approval process. As there is no measurement system tested by mathematical data, the system is observed by using qualitative gage R&R analysis.

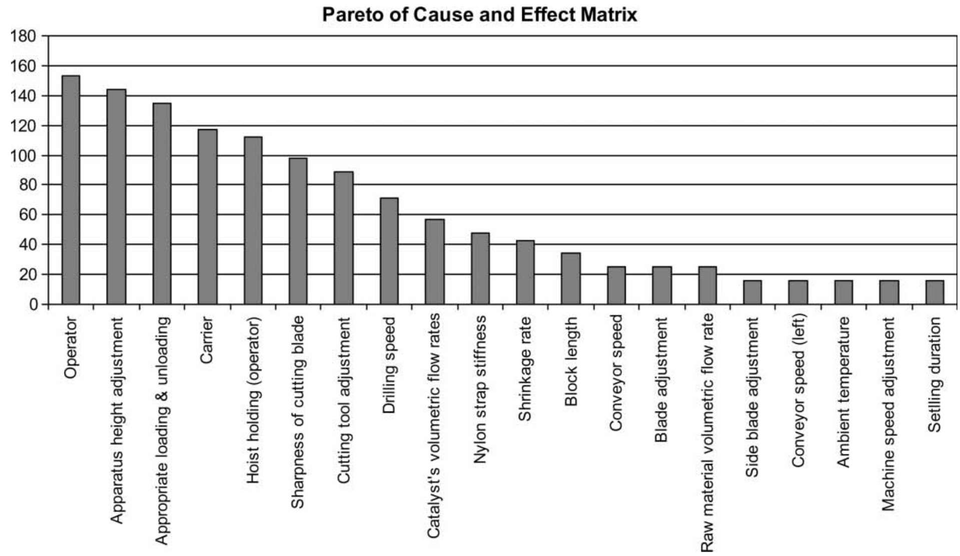

Figure 4. Pareto diagram of cause and effect matrix.

Table 2. Data collection plan.

		Data type	Specification	Measurement method	C_{pk}/ importance
Output	Shell scrap	Measureable	Daily	Volume (m^3) and formulation	0.33
Input	Lamination process operator	Qualitative	Foam is visually ok/ not ok	Observation	High importance
Input	Appropriate loading/ unloading	Qualitative	Ok/not ok	Observation	High importance
Input	Drilling apparatus height adjustment	Measurable	For each foam block	Length (m)	Low importance

The method applied for this MSA study is as follows:

- Twenty laminated foam pieces are obtained for measurement and these pieces are given numbers. In another list, not seen by the operators, the visual quality of each piece is written.
- It is required from each operator to look at the pieces and make comments for each piece. This process is repeated once again the next day.

The test is performed over 20 pieces in a total of 2 rounds with 2 lamination process operators. This assessment shows that all operators' assessments agree with the known standard with a ratio of 70%. The comparison of each operator is given in Table 3. During the MSA study, it has been concluded that the measurement system is not sufficient, and the operators need to be trained. As it can be seen from this table, the operators need to be evaluated once more after training.

As indicated above, the operators needed a training programme before consistent data collection for the project could be commenced. For this purpose, a detailed training programme for these operators have been prepared and conducted. Then the same analyses as it was accomplished before have been repeated after this training period. It is observed that

Table 3. Initial quantitative gage R&R study results.

		Operator 1			Operator 2		
Sample	Expert	First Observation	Second Observation	Y/N	First Observation	Second Observation	Y/N
1	Ok	Ok	Ok	Y	Not ok	Not ok	N
2	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
3	Not ok	Not ok	Not ok	Y	Not ok	Ok	N
4	Not ok	Not ok	Ok	N	Not ok	Not ok	Y
5	Ok	Ok	Ok	Y	Ok	Ok	Y
6	Ok	Ok	Ok	Y	Ok	Ok	Y
7	Ok	Ok	Ok	Y	Ok	Not ok	N
8	Ok	Ok	Ok	Y	Ok	Ok	Y
9	Ok	Ok	Ok	Y	Ok	Ok	Y
10	Ok	Ok	Ok	Y	Ok	Ok	Y
11	Not ok	Not ok	Ok	N	Not ok	Not ok	Y
12	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
13	Ok	Ok	Ok	Y	Ok	Ok	Y
14	Ok	Ok	Ok	Y	Not ok	Ok	N
15	Ok	Ok	Ok	Y	Ok	Ok	Y
16	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
17	Ok	Ok	Ok	Y	Ok	Ok	Y
18	Ok	Ok	Ok	Y	Ok	Ok	Y
19	Not ok	Not ok	Not ok	Y	Not ok	Ok	N
20	Ok	Ok	Ok	Y	Ok	Not ok	N
Results		18/20 = 90%		90%	14/20 = 70%		70%

the operators performed much better than the previous results and the improvement reached to 90%. Furthermore, there is some improvement about their consistency between each other. The final case can be seen in Table 4.

After the MSA study, related data of the production for the last 3 months are collected and analysed. This data collection includes the following:

- operator name, date and shift;
- foam production number;
- foam block number;
- block height;
- the operators also include the volume information of the scrap and the total production length of the laminated foam. Sample 'data processing form' can be seen in Table 5.

The process capability, C_{pk}, of shell scrap percentage is calculated with the initial data and found to be 0.33. The process capability can be seen in Figure 5. Additionally, the C_p value of the process is found to be 0.72. Although the process capability values C_p and C_{pk} are desired to be above 1.33 in general (Montgomery, 2005), in this application the process capabilities are used to simplify the comparison of the process before and after the improvements. Therefore, from Figure 5, it is concluded that process average value is away from the target value indicating that process capability is insufficient and process variation must be decreased.

Initial analysis of the collected data is performed. In this analysis, the Pareto chart of Figure 6 provides the distribution of volume of scrap according to customers. In this figure, it is seen that 'Customer A' has 72.6% of the total scrap volume, and 'Customer A + Customer D' have 86.2% of the total scrap volume.

Table 4. Final quantitative gage R&R study results.

Sample	Expert	Operator 1 First Observation	Operator 1 Second Observation	Y/N	Operator 2 First Observation	Operator 2 Second Observation	Y/N
1	Ok	Ok	Ok	Y	Ok	Ok	Y
2	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
3	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
4	Not ok	Not ok	Ok	N	Not ok	Not ok	Y
5	Ok	Ok	Ok	Y	Ok	Ok	Y
6	Ok	Ok	Ok	Y	Ok	Ok	Y
7	Ok	Ok	Ok	Y	Ok	Ok	Y
8	Ok	Ok	Ok	Y	Ok	Ok	Y
9	Ok	Ok	Ok	Y	Ok	Ok	Y
10	Ok	Ok	Ok	Y	Ok	Ok	Y
11	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
12	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
13	Ok	Ok	Ok	Y	Ok	Ok	Y
14	Ok	Ok	Ok	Y	Ok	Ok	Y
15	Ok	Ok	Ok	Y	Ok	Ok	Y
16	Not ok	Not ok	Not ok	Y	Not ok	Not ok	Y
17	Ok	Ok	Ok	Y	Ok	Ok	Y
18	Ok	Ok	Ok	Y	Ok	Ok	Y
19	Not ok	Not ok	Not ok	Y	Not ok	Ok	N
20	Ok	Ok	Ok	Y	Ok	Not ok	N
Results		19/20 = 95%		95%	18/20 = 90%		90%

Table 5. Data processing form template.

No.	Date	Shift	Operator ID	Density	Production no.	Block no.	Foam block length (cm)	Thickness (mm)	Total production (m)	Scrap (m^3)
1	23.06.2005	1	377	...	2005-50	1	155	10.8	90	0.225
2	23.06.2005	1	377	...	2005-50	2	185	3.2	280	0.500
3	23.06.2005	2	122	...	2005-50	3	142	7.0	150	0.260
4	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...

The measurement phase is completed with these results. In the next section, in the analysis phase, the data collected after the measure phase is analysed.

2.3. *Analysis phase*

The analysis phase consists of three main steps:

(1) process and multivariate analysis;
(2) identifying possible causes;
(3) verification through hypothesis tests.

In the process and multivariate analysis step, one aims to identify the related inputs for the selected output of the process. Obviously some of the related inputs can be diagnosed

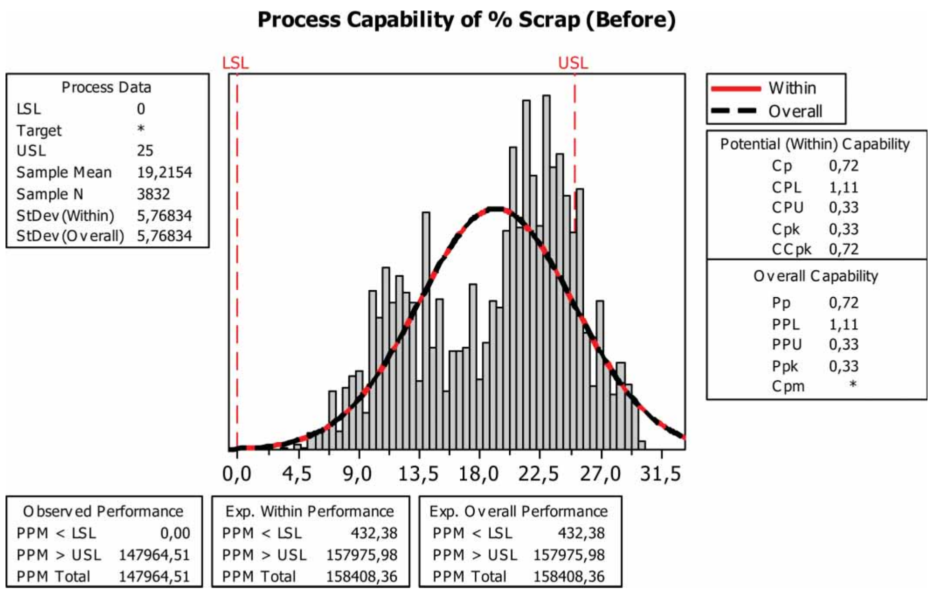

Figure 5. Process capability in initial state.

as just noise, and it is impossible to improve these inputs. Therefore, the aim is to identify the inputs that are called the process parameters.

During this step of the analysis, the project team realised that during the drilling process there is an eccentricity problem of the foam block. Because this problem does not require further analysis and can be eliminated simply, it is decided to improve the process right at this point. Therefore, the proceeding data will have smaller variance rooting from this eccentricity problem. So in the following parts of this study, the data collected after this improvement is labelled as after 'first improvement'.

For the process at hand, the output 'scrap percentage' is analysed with respect to the inputs, foam block length, foam production lot, laminated foam thickness and customers.

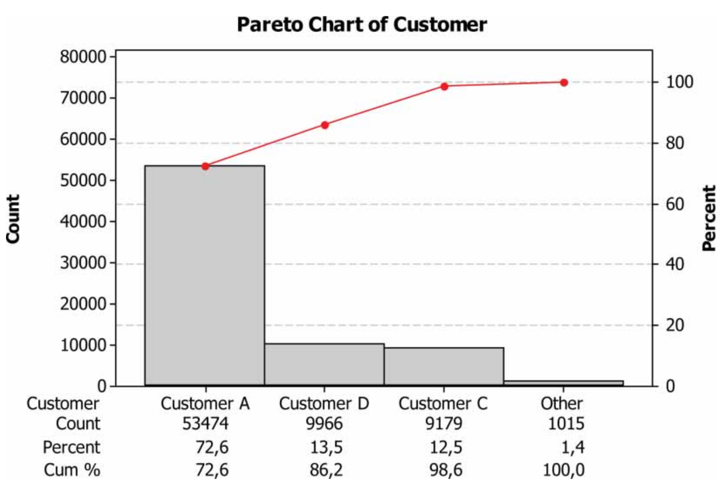

Figure 6. Pareto diagram of volume of scrap.

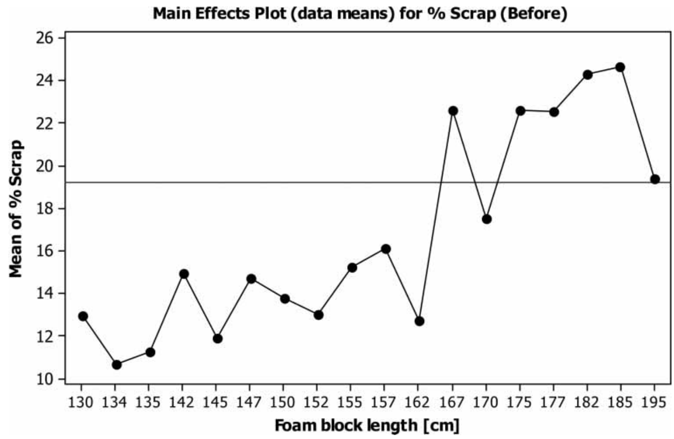

Figure 7. Main effects plot for percent scrap versus foam block length.

The results of these analyses can be seen through Figures 7–10. The results indicate that the three inputs, that is, foam block length, laminated foam thickness and customers are the related possible causes of high scrap percentage.

In Figure 7, scrap percentage versus foam block length relation can be seen. As seen in the figure, foam block length of 165 cm is critical. After this length, the scrap percentage increases significantly.

In Figure 8, scrap percentage versus foam production lot relation can be seen. It can be concluded that there is no apparent relationship of this input to the scrap percentage.

The scrap percentage versus laminated foam thickness can be seen in Figure 9. As seen in this figure, there is a significant scrap percentage increase for laminated foam thicknesses of 3, 3.2 and 3.5 mm. There is also an increase in the thickness of 17.5 mm but this point should not be included in the analysis as this thickness value is not in mass production.

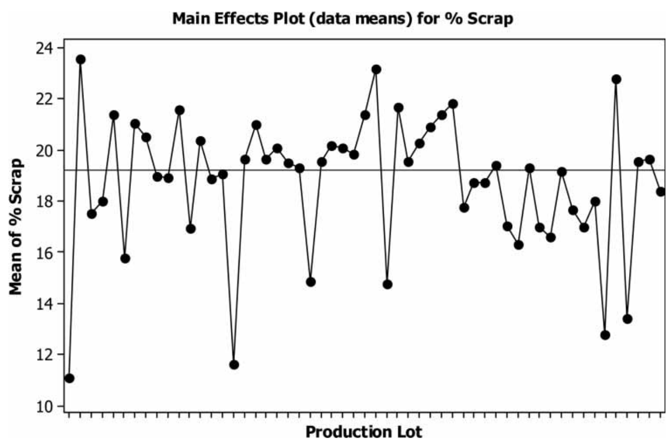

Figure 8. Main effects plot for percent scrap versus production lot.

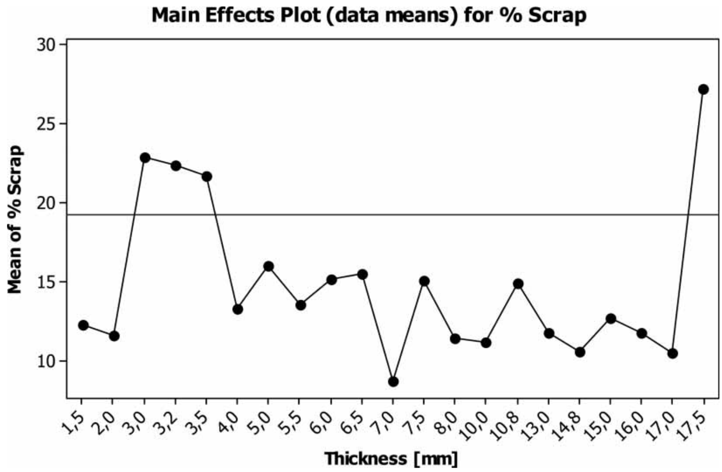

Figure 9. Main effects plot for percent scrap versus laminated foam thickness.

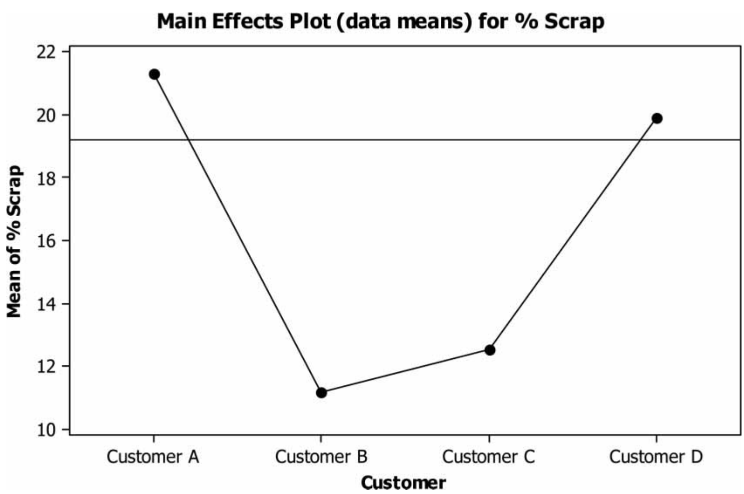

Figure 10. Main effects plot for percent scrap versus customers.

In Figure 10, scrap percentage versus customers are shown. It's observed that the products produced for Customers A and D have higher scrap percentages.

After analysing Figures 7 and 9, it is decided to group the data in order to achieve significant results. For this purpose, foam blocks that have length less than 160 cm are grouped as 'short' and foam blocks that have greater length are grouped as 'long'. A similar approach is performed on laminated foam thickness, and laminated foams thicker than 11 mm are grouped as 'thick', laminated foams having a thickness between 4 and 11 mm are grouped as 'medium' and laminated foams having a thickness less than 4 mm are grouped as 'thin'. The results can be seen in Figure 11. As seen in this figure, foam blocks that are considered as 'long' and laminated as 'thin' have the largest scrap percentage, which is about 22.7%. Additionally, the foam blocks that are laminated 'thick' are robust to block length. These results indicate

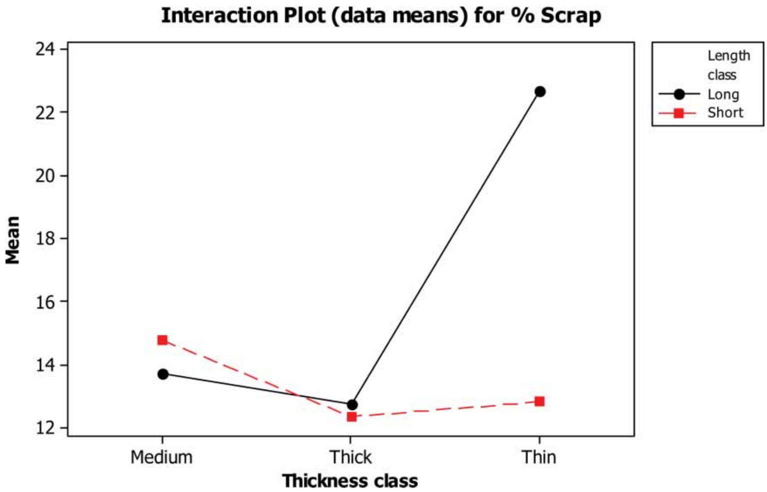

Figure 11. Interaction plot for percent scrap for length and thickness.

that the improvement can be accomplished for long foam blocks that are laminated as thin.

2.4. *Improvement phase*

The aim of the improvement phase is to examine the reasons which appear during the analysis phase and to generate a set of solutions to improve the performance of the process. As a result, the team members list the following improvements to the identified root causes:

- One of the lamination process operators is diagnosed as inexperienced. In order to solve this problem, the operator is trained by the experts and the gage R&R study is repeated. This improvement is accomplished during the measure phase.
- As indicated before, in the early stages of analysis, it was determined that during the drilling process there was an eccentricity problem of the foam block. In order to eliminate this problem, a special apparatus is designed for better eccentricity. This improvement is accomplished during the analysis phase.
- The reasons of long foam blocks' having higher shell scrap percentage are identified as follows:
  (i) inappropriate length of the carrier;
  (ii) problems with settling process, that is, dimension and shape deformations during settling;
  (iii) inappropriate handling of the foam block during loading/unloading.

These three problems are solved, respectively, as follows:

(i) A special carrier having sufficient length is designed, prototyped and after sufficient tests the carrier is manufactured.
(ii) The settling method is improved. The above designed carrier also has properties to support this improved settling method.
(iii) A special hoist system is implemented. This new system holds the foam sufficiently without damaging its outer side.

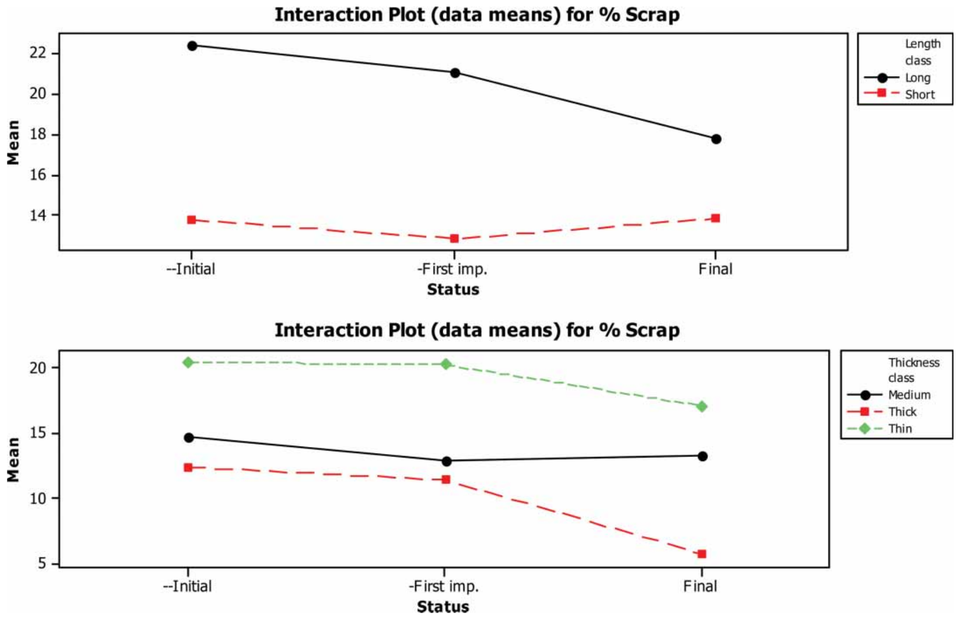

Figure 12. Interaction plots for comparison.

These improvements are applied all at the same time. The improvement results reveal the following: Figure 12 provides two subplots, the upper for length class and the lower for thickness class. As it can be seen in the length class subplot, there is no significant change in scrap percentage for 'short' foam blocks. Furthermore, there is approximately 4% decrease in scrap percentage for 'long' foam blocks. On the other hand, the thickness class subplot indicates that there is approximately 6.5% decrease in scrap percentage

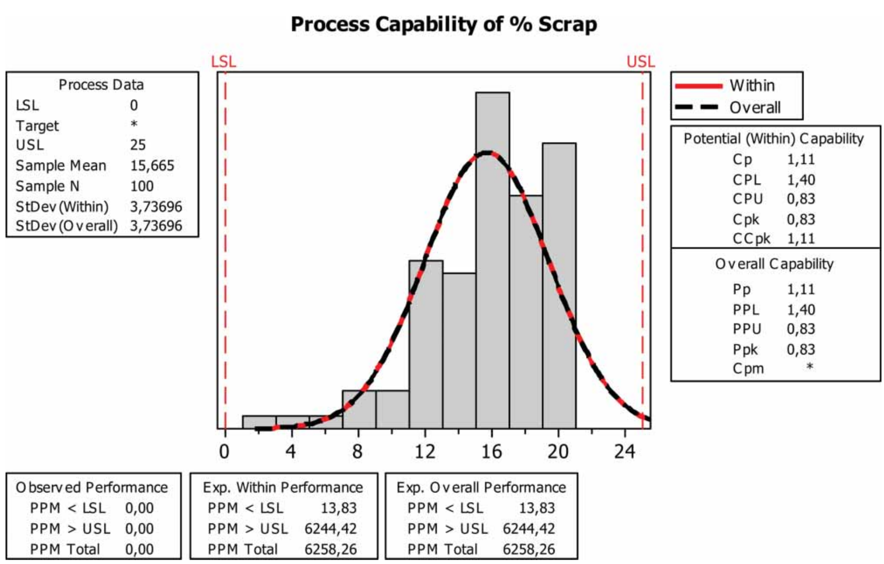

Figure 13. Process capability in final state.

Table 6. Comparison of the process.

	Initial state	After first improvement	After all improvements
ppm	158,408	114,674	6258
Sigma level	2.5σ	2.7σ	4σ
Scrap mean	19.215	18.250	15.665
Scrap deviation	5.768	5.601	3.728

for 'thick' laminated foams, and approximately 3.5% decrease for 'thin' laminated foams. There is no significant change for 'medium' laminated foams.

After the implementations, the process capability is calculated and evaluated. The new capability plot can be seen in Figure 13. As it can be seen from this figure, the C_{pk} is increased to 0.83 and the C_p is increased to 1.11. Additionally, Table 6 indicates the change in the process indicators before and after improvements. It is concluded that the sigma level has increased to 4-sigma value from 2.5-sigma value for this specific process. The ppm (parts per million) value also decreases to 6258 from 158,408. For further comparison, scrap percentage change is also given in Table 6. This table indicates an improvement of 3.550%, from 19.215 to 15.665, which is greater than the project target of 2%.

These results indicate that the sigma level and also the ppm value meet requirements of the customers and the management. But it is necessary to decide whether these solution alternatives will be selected or not, after the hypothesis test. For this process, it is suitable to compare the data of 'initial', after 'first improvement' and 'final' states by using ANOVA and test for equal variances.

For this purpose, first it is necessary to construct *H0* and *H1* hypothesis by using means (μ) and standard deviations (σ):

$$H0{:}\mu_{\text{initial}} = \mu_{\text{firstimprovement}} = \mu_{\text{final}} - \{\text{Reject}\},$$

$$H1{:}\mu_{\text{initial}} \neq \mu_{\text{firstimprovement}} \neq \mu_{\text{final}} - \{\text{Approve}\},$$

and

$$H0{:}\sigma_{\text{initial}} = \sigma_{\text{firstimprovement}} = \sigma_{\text{final}} - \{\text{Reject}\},$$

$$H1{:}\sigma_{\text{initial}} \neq \sigma_{\text{firstimprovement}} \neq \sigma_{\text{final}} - \{\text{Approve}\}.$$

The results of test for equal variances are given in Table 7. As it can be seen from this table, the *p*-value for Bartlett's test is zero, which indicates the rejection of *H0* for standard

Table 7. Test for equal variances.

Test for equal variances: % scrap versus before/after				
95% Bonferroni confidence intervals for standard deviations				
Before/after	*N*	Lower	Standard deviation	Upper
Initial	3832	5.6142	5.768	5.92991
First improvement	2318	5.4104	5.601	5.80475
Final	100	3.1825	3.728	4.48169
Bartlett's test (normal distribution): test statistic = 29.71; $p = 0.000$				
Levene's test (any continuous distribution): test statistic = 17.58; $p = 0.000$				

Table 8. ANOVA for scrap mean comparison.

One-way ANOVA: % scrap versus before/after					
Source	DF	SS	MS	F	P
Before/after	2	2344.3	1172.2	36.34	0
Error	6247	201,517.8	32.3		
Total	6249	203,862.1			
$S = 5.680$	$R^2 = 1.15\%$		R^2(adj) = 1.12%		

Level	N	Mean	Standard deviation	Individual 95% CIs for mean based on pooled standard deviation ––+–– ––––+–– ––+–– ––+––
Initial	3832	19.215	5.768	(*)
First improvement	2318	18.25	5.601	(-*)
Final	100	15.665	3.728	(––––*––––)
				––+–– ––+–– ––––+–– ––+––––
Pooled standard deviation = 5.680				15.0 16.5 18.0 19.5

deviations. Therefore, the three states have different standard deviations with the 'final' state having the smallest value.

On the other hand, ANOVA results are given in Table 8. It is observed from the table that the p-value is zero. Therefore, once more, $H0$ is rejected for means. This result indicates that, the three states have different means with the 'final' state having the smallest value.

These results provide the validity of the improvements.

2.5. *Control phase*

Usually, the control phase is regarded as the most important phase of the Six Sigma methodology. At this phase, all the improvements that are realised at the preceding four phases are investigated and their stability should be maintained. Since all improvements, except the operator training, are related to various tooling and completed in improvement phase, the aim of the control phase for this project is to standardise the usage of improved tools.

For this purpose, first of all achieved profit levels after the improvements are evaluated and in order to keep this profit stable and to increase it, if possible, the scrap percentage levels are monitored continuously by the production department and included in the important indicator list by the management.

On the other hand, for the operator training, the gage R&R study is included in yearly action plans.

3. Conclusions

Six Sigma is an essential continuous improvement method that aims to reduce the variation and waste on industrial processes. In this paper, a detailed application of Six Sigma methodology for reducing the shell scrap of foam production and lamination process is explained. The DMAIC phases of Six Sigma and their results are indicated in great detail. Several statistical tools and techniques were engaged during the path of the project. As a result of the approach, the process capabilities and the sigma levels increased, and shell scrap percentage decreased. The average decrease is around 3.5% which is greater than the project target of 2%. Additionally, the financial benefit of this project is approximately $45,000 per year. In addition to these results, expected benefits such as increase in operational profitability, increase in production capacity, reduction of scrap stock area and reduction of cycle time were also obtained. Furthermore, better process knowledge and use of statistical thinking to solve engineering problems are also attained.

References

Aksoy, B., & Orbak, A.Y. (2009). Reducing the quantity of reworked parts in a robotic arc welding process. *Quality and Reliability Engineering International*, *25*(4), 495–512.

Antony, J., Kumar, M., & Tiwari, M.K. (2005). An application of Six Sigma methodology to reduce the engine-overheating problem in an automotive company. *Proceedings of the Institution of Mechanical Engineers (IMechE), Part B. Journal of Engineering Manufacture*, *219,* 633–646.

ASQ. (2002). The Honeywell edge. *Six Sigma Forum Magazine*, *1*(2), 14–17.

Banuelas, R., Antony, J., & Warwick, M.B. (2005). An application of Six Sigma to reduce waste. *Quality and Reliability Engineering International*, *21,* 553–570.

Barney, M., & McCarty, T. (2002). *The new Six Sigma: A leader's guide to achieving rapid business improvement and sustainable results*. Upper Saddle River, NJ: Prentice Hall, PTR.

Brady, J.E., & Allen, T.T. (2005). Six Sigma literature: A review and agenda for future research. *Quality and Reliability Engineering International*, *22,* 335–367.

Breyfogle, F.W., III. (1999). *Implementing Six Sigma: Smarter solutions using statistical methods*. Hoboken, NJ: Wiley.

Chowdhury, S. (2003). *Design for Six Sigma*. Upper Saddle River, NJ: Prentice Hall.

Coronado, B., & Antony, J.R. (2002). Critical success factors for the successful implementation of Six Sigma projects in organizations. *The TQM Magazine*, *14*(2), 92–99.

Dahlgaard, J.J., & Dahlgaard-Park, S.M. (2006). Lean production, Six Sigma quality, TQM and company culture. *The TQM Magazine*, *18*(3), 263–281.

Eckes, G. (2003a). *Six Sigma for everyone*. Hoboken, NJ: John Wiley & Sons.

Eckes, G. (2003b). *Six Sigma team dynamics. The elusive key for project success*. Hoboken, NJ: John Wiley & Sons.

Goh, T.N., & Xie, M. (2003). Statistical control of a Six Sigma process. *Quality Engineering*, *15*(4), 587–592.

Harry, M.J., & Schroeder, R. (2002). *Six Sigma: The breakthrough management strategy revolutionizing the world's top corporations*. New York, NY: Doubleday Business.

Hoerl, R.W. (1998). Six Sigma and the future of quality profession. *Quality Progress*, *6,* 35–42.

Hoerl, R.W. (2001). Six Sigma black belts: What do they need to know. *Journal of Quality Technology*, *33*(4), 391–406.

Kwak, Y.H., & Anbari, F.T. (2006). Benefits, obstacles, and future of Six Sigma approach. *Technovation*, *26,* 708–715.

McClusky, R. (2000). The rise, fall, and revival of Six Sigma. *Measuring Business Excellence*, *4*(2), 6–17.

Montgomery, D.C. (2005). *Introduction to statistical quality control* (5th ed.). Hoboken, NJ: Wiley.

Pande, P.S., Neuman, R.P., & Canavagh, R.R. (2000). *The Six Sigma way*. NewYork, NY: McGraw-Hill.

Pyzdek, T. (2003). *The Six Sigma project planner*. New York, NY: McGraw-Hill.

Slater, R. (1999). *Jack Welch and the GE Way: Management insights and leadership secrets of the legendary CEO*. New York, NY: McGraw-Hill.

Yang, K., & El-Haik, B. (2003). *Design for Six Sigma: A roadmap for product development*. New York, NY: McGraw-Hill.