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Lean Six Sigma Application in Rear Combination Automotive Lighting Process

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Abstract. The case study company produces various front and rear lightings for automobiles and motorcycles. Currently, it faces two problems, i.e. high defective rate and high inventory. Lean Six Sigma was applied as a tool to solve the first problem, whereas the other problem was managed by changing the production concept from push to pull. The results showed that after applying all new settings to the process, the defect rate was reduced from 36,361 DPPM to 3,029 DPPM. In addition, after the implementation of the Kanban system, the company achieved substantial improvement in lead time reduction by 44%, in-process inventory reduction by 42%, finished good inventory reduction by 50%, and finished good area increased by 16%.

1. Introduction

Automotive parts industry is vital to the growth of national economy. Part manufacturing companies search for management methodologies that allow them to improve their products and processes, decrease cost, increase profitability and customer's satisfaction. The case study company is a large-sized automotive lighting manufacturer in Thailand. The company produces high varieties of front and rear lightings supplying to automotive and motorcycle assembly companies.

Preliminary production survey indicates that the rear combination automotive lighting of the T9 product has highest defects (10,762 DPPM) comparing with other models resulting from high process wastes. This results in its current production cost being found substantially higher than its selling price. As a result, in this paper, the Lean Six Sigma method [1-7] is applied to reduce defects in the T9 manufacturing process.

The steps of Lean Six Sigma include the waste identification (7 wastes), as well as the defect waste reduction in process injection (5 phases of the Six Sigma approach, i.e. DMAIC standing for define, measure, analysis, improvement and control phases).

2. Define Phase

This research focuses on the production of the T9 model of the rear combination automotive lighting since its defect rate is highest. The production of the T9 model consists of three processes, i.e.

injection, surface, and assembly. From the historical defect reports between January 2015 and July 2015, it was found that the injection process had the highest defect rate of 36,361 DPPM comparing with the others. In addition, the injection process is the first process in which can cause several consequence effects to the two subsequence processes. Four major defects found in the injection process include silver line (39.8%), dust (19.3%), short shot (15%), and flash (7.4%). As a result, the application of Lean Six Sigma is emphasized on the highest defect proportion, i.e. silver line defect.

3. Measure Phase

This phase involves two main steps, i.e. waste measurement and problem identification analysis, which can be described as follows [6].

3.1 Waste Measurement

Based on the 7-wastes concept, wastes can be arisen from over production, unnecessary transportation, waiting, unnecessary inventory, defects, unnecessary motions, and inappropriate processing [2, 3]. The result of the waste assessment of the T9 model is shown in Table 1. It is obvious that the types of wastes that influence most to the T9 model include defects (37.70%), over production (31.39%), and unnecessary inventory (16.39%).

Table 1. Summary of Waste Measurement.

No.	Types of waste	Frequency (%)
1	Over production	31.39
2	Unnecessary transportation	4.11
3	Waiting	5.34
4	Unnecessary Inventory	16.39
5	Defects	37.70
6	Unnecessary motions	1.42
7	Inappropriate operation	3.65

Currently, the T9 model manufacturing process is run based on the push production concept [8] where the forecasted schedule is used to determine the production quantity to be produced in each month. The major steps of the T9 model manufacturing process are sketched as shown in Figure 1.

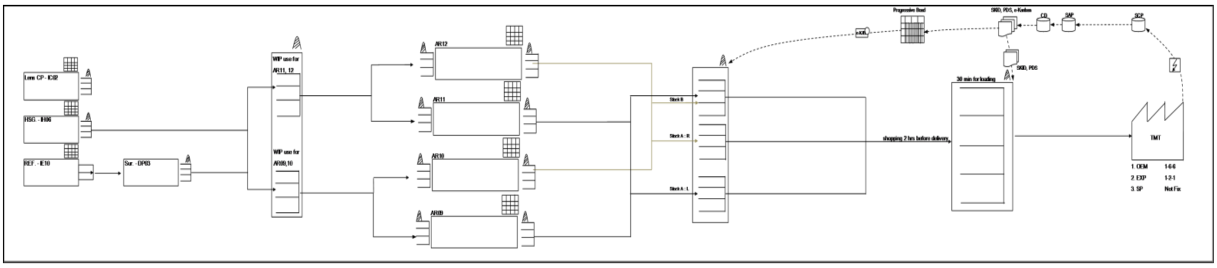

Figure 1. Major steps of the T9 model manufacturing process.
(Note: Manufacturing process is run based on the push production concept. The processes comprises injection, surface and assembly)

3.2 Problem Identification Analysis

A number of brainstorming meetings by a knowledgeable team who specializes in the production process of the rear combination automotive lighting were systematically conducted to indicate the relevant factors that can affect defects occurred in the injection process. The cause and effect analysis with 5M1E was applied in this process [3]. It was revealed that the number of tentative causes was 16 (Table 2). These factors were used for further analyzing the relationship between cause and related effect using the cause and effect matrix. By scoring these relationships (i.e. 0, 1, 3, and 9), these scores were sorted from large to small by the Pareto chart and the factors with significant impacts (high score is 9) were selected for further analysis. As a result, the relevance factors were reduced to 7 (Fig. 2).

Table 2. Cause and Effect Diagram with 5M1E.
(Source: Brainstorm meetings by a knowledgeable team who specializes in the production process of the rear combination automotive lighting.)

Item	Area cause	Process input	Total
1	Man	Operators lack of training	3
2		Operators lack of knowledge	1
3		Operators lack of experiences and skills	1
4	Material	Quality of plastic	3
5	Machine	Design of mold does not fit	9
6		Machine breakdown	9
7		Clamping force for injection molding	3
8		Screw and Barrel are corroded	3
9	Method	Time of bake plastic	9
10		Temperature of bake plastic	9
11		Speed of injection	9
12		Pressure of injection	9
13		Time of cooling part	9
14	Measurement	Measurement system instability	3
15	Environment	Humidity in working area	3
16		Temperature in working area	0

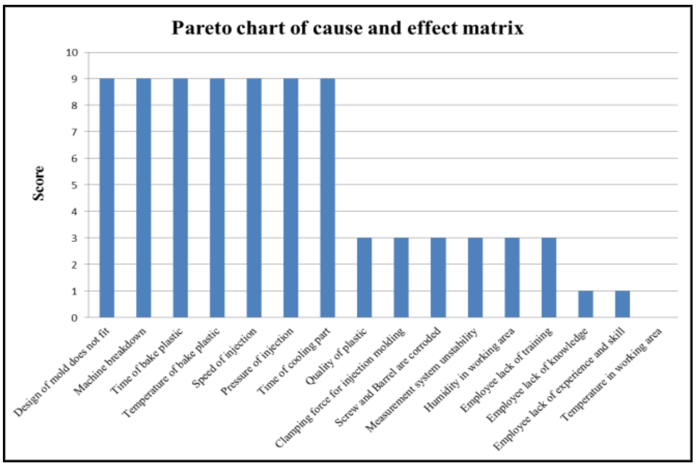

Figure 2. Pareto chart of Cause and Effect matrix.

The root causes with the highest score (9 points from Figure. 2) were selected for further analyze the factors that had significant impacts to the silver line defect. The risk priority number of each root cause was calculated (Table 3).

Table 3. The Risk Priority Number of Each Root Cause.

No.	Potential Failure	Risk Priority Number (RPN)
1	Design of mold does not fit	108
2	Machine breakdown	120
3	Time of bake plastic	486
4	Temperature of bake plastic	648
5	Speed of injection	720
6	Pressure of injection	648
7	Time of cooling part	448

Fig. 3 shows five potential factors that were concluded from the brainstorming meetings including speed of injection, pressure of injection, temperature of bake plastic, time of bake plastic and time of cooling part. The result shows that five factors have a high score. As a result, these five factors were selected for experiments in the next phase, which was 96% of the total score.

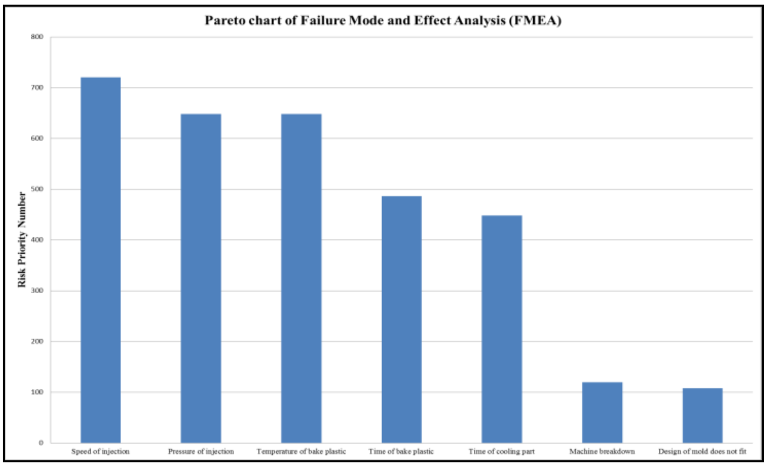

Figure 3. Pareto chart of Failure Mode and Effect Analysis.

4. Analysis Phase

The 2k-1 fractional factorial design [11] was employed to test whether or not these factors and their interactions have significant impacts on the silver line defect (Table 4). The levels of each factor were mainly chosen from the minimum and maximum adjustable values of the instruments used in the process. All 16 trials were conducted within a completely randomized experiment. The response variable in this study was the defect occurred in the injection process.

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Table 4. Factors and Level of Factors in 2^{5-1} Fractional Factorial Design.

No.	Factors	Units	Symbols	Levels of factor	
				Low (-1)	High (1)
1	Speed of injection	percentage	A	10	20
2	Pressure of injection	kilograms/square centimeter	B	150	160
3	Temperature of bake plastic	Celsius	C	90	100
4	Time of bake plastic	hour	D	3	4
5	Time of cooling part	second	E	25	30

The experimental data were analyzed by using the Minitab software and the Pareto chart of effects (Fig. 4). The factor effect with its value greater than 0.1588 is a significant factor at 95% confident interval. The Pareto chart of effects showed that main effects A and B have the P-values less than 0.05 (significant level α), whereas factors C, D, E and interactions (AB, AC, AD, AE, BC, BD, BE, CD and DE) were not significant. Therefore, it can be concluded that the main effects A and B are significant at 95% confident interval. As a result, all significant factors need further investigation to find their appropriate level settings.

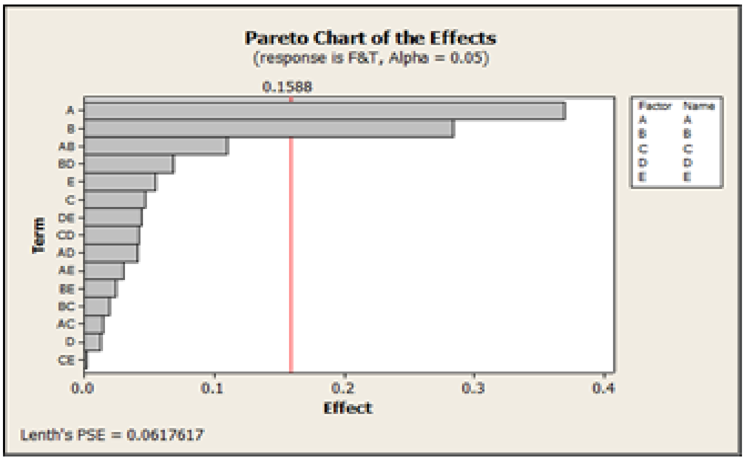

Figure 4. Pareto chart of effects.

5. Improvement Phase

The 2k-1 fractional factorial design [11] was employed to test whether or not these factors and their interactions have significant impacts on the silver line defect (Table 4). The levels of each factor were mainly chosen from the minimum and maximum adjustable values of the instruments used in the process. All 16 trials were conducted within a completely randomized experiment. The response variable in this study was the defect occurred in the injection process.

5.1 Experiment of relevant parameter

In this phase, more levels of the significant factors derived from the 2k-1 fractional factorial experiments were tested to find their appropriate levels that can reduce defects in the injection process of the rear combination automotive lighting. The general full factorial design was used in this experiment. Three levels of the speed of injection (A) and three levels of the pressure of injection (B) were randomly run with 2 replicates (Table 5).

Table 5. Factors and Levels of Factors in Factorial Experimental Design

No.	Factors	Units	Symbols	Levels of factor		
				Low (-1)	Medium (0)	High (1)
1	Speed of injection	percentage	A	10	15	20
2	Pressure of injection	kilograms/square centimeter	B	150	155	160

The statistics [12] in Figure. 5 shows that the main effects and two-way interaction have the P-values less than 0.05. Therefore, it can be concluded that the main effects and two-way interaction affected the defects in the injection process at 95% confident interval. Since the interaction effects were significant, the interaction effect plots were used as a mean to select the proper settings for the factors (Fig. 6). Hence, Factor A (speed of injection) was set at 20 percentage (high level of factor A), whereas Factor B (pressure of injection) was set at 155 kilograms/square centimeter (medium level of factor B).

General Linear Model: F&T versus Speed, Pressure

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Factor    Type   Levels  Values
Speed     fixed       3  10, 15, 20
Pressure  fixed       3  150, 155, 160


Analysis of Variance for F&T, using Adjusted SS for Tests

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Speed            2  0.060924  0.060924  0.030462  43.89  0.000
Pressure         2  0.022163  0.022163  0.011082  15.97  0.001
Speed*Pressure   4  0.037044  0.037044  0.009261  13.34  0.001
Error            9  0.006246  0.006246  0.000694
Total           17  0.126377


S = 0.0263439   R-Sq = 95.06%   R-Sq(adj) = 90.66%
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Figure 5. Results of Analysis of Variance.

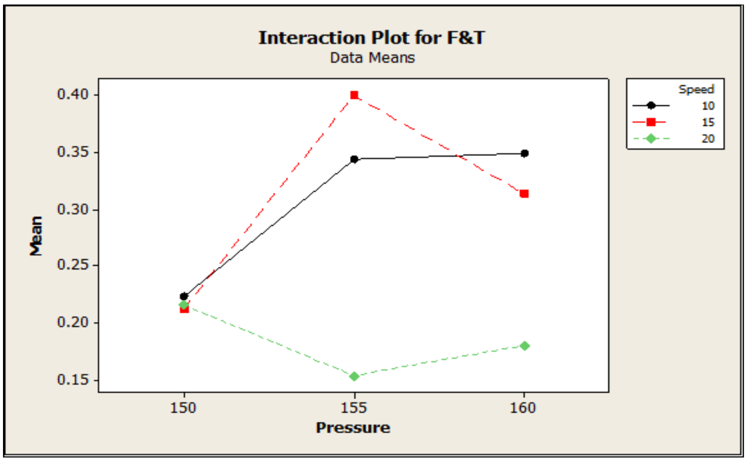

Figure 6. Interactions Effects Plot.

5.2 Pull concept implementation

Since the company applies the push production concept, the finished products are produced according to the forecasted demand without consideration of the actual customer's requirements. Consequently, huge amount of WIP parts were found stagnated on the shop floor and the warehouse was fully packed with unnecessary finished goods. Because of the unorganized and less shop floor space, the congested material flow was noticeable in every production day.

To overcome this problem, the company decided to apply the pull production concept by implementing the Kanban system in the manufacturing process [9, 10]. It was also expected that this concept could bring about the reduction of inventory in the warehouse (Fig. 7).

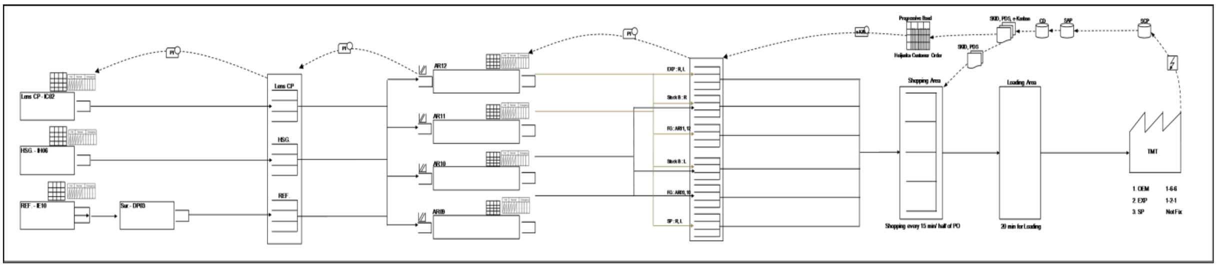

Figure 7. Development of the T9 model manufacturing process by Kanban system.

Before the Kanban pull system was realized on the shop floor, establishing of the mechanism and rule were necessary in order to assist the Kanban activity. The Kanban card was designed and issued to the production process (Figs. 8 and 9).

Figure 8. Example of Kanban cards: Production Instruction Kanban card

Figure 9. Example of Kanban cards: Part Withdrawal Kanban card with container

Fig. 8 shows that the production instruction Kanban card is a production order, which gives the instruction to the production process to produce the required product according to the needed quantity. In addition, the production withdrawal Kanban card (Fig. 9) is the authorization signal for the withdrawal of the product from the production process according to customer's needs.

The Kanban cards contain required information for the production process. To ensure that they are producing the right part in the right quantity at the right time according to customer's needs. The following information is contained in the Kanban card including customer information (such as customer's name), customer product name and type of model, product information (such as part name, part picture, and quantity per packing), production process address and storage area.

The Heijunka post used as the planning schedule to evenly distribute the product volume and variety throughout available production time was also established. Every Kanban card that was detached from the container during the withdrawal process was loaded into the Heijunka post. The card at the Heijunka post was used to withdraw the product from the production process to replenish the finished good that had been delivered to the customer. The frequency of withdrawal is scheduled according to the takt time. Therefore, Heijunka prevent the uneven loading of volume occurred in the production floor. To establish this post, few operational settings had to be determined, e.g. frequency of the withdrawal process and conveyance time, quantity of the Heijunka slot, maximum production quantity, etc.

6. Control Phase

In this phase, all settings of the significant factors derived from the previous phase were implemented in the process and the data relating to the defect occurred in the injection process of the rear combination automotive lighting were collected for 30 days. It was found that the quantity of defects was reduced substantially. The comparison between the number of defects before and after the improvement process was shown in Figs. 10 and 11.

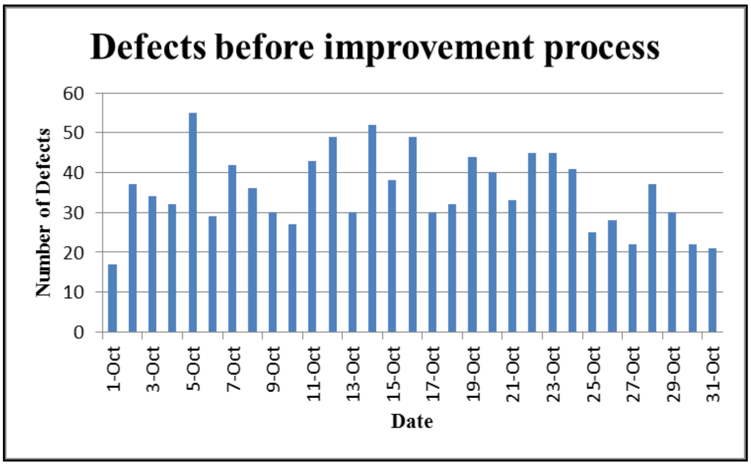

Figure 10. Defects before improvement injection process of the T9 model.

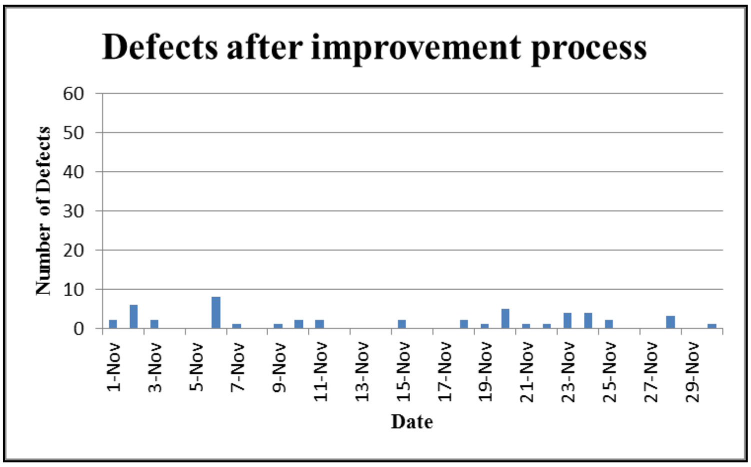

Figure 11. Defects after improvement injection process of the T9 model.

To maintain the quality of the injection process after the improvement, the work instruction for operational control in the injection process was written. In addition, the operators were trained to understand the importance of controlling these parameters to ensure that the performance improvements were maintained. In addition, to control these Kanban activities, a Kanban rule was established. The documented information related to all the guidelines and references was written and shared among all the production personnel that were involved in this activities. This helped the operators to manage and monitor the Kanban activities systematically.

7. Conclusion

The Lean Six Sigma method was applied to reduce wastes that occurred in the rear combination automotive lighting of the T9 manufacturing process. Currently, it faces two problems, i.e. high defective rate and high inventory. Five steps of the Six Sigma were systematically utilized so as to find the proper parameter settings of the significant factors. It was found that the speed of injection and pressure of injection had significant effects on the problem of interest. After applying all new settings to the process, the defect rate was reduced to 3,029 DPPM. In addition, after the implementation of the Kanban system, the company achieved substantial improvement in lead time reduction by 44%, in-process inventory reduction by 42%, finished good inventory reduction by 50%, and finished good area increased by 16%.

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