Six Sigma Solutions and its Benefit-Cost Ratio for Quality Improvement

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***Abstract*—**This is an application research presenting the improvement of production quality using the six sigma solutions and the analyses of benefit-cost ratio. The case of interest is the production of tile-concrete. Such production has faced with the problem of high nonconforming products from an inappropriate surface coating and had low process capability based on the strength property of tile. Surface coating and tile strength are the most critical to quality of this product. The improvements followed five stages of six sigma solutions. After the improvement, the production yield was improved to 80% as target required and the defective products from coating process was remarkably reduced from 29.40% to 4.09%. The process capability based on the strength quality was increased from 0.87 to 1.08 as customer oriented. The improvement was able to save the materials loss for 3.24 millions baht or 0.11 million dollars. The benefits from the improvement were analyzed from (1) the reduction of the numbers of non conforming tile using its factory price for surface coating improvement and (2) the materials saved from the increment of process capability. The benefit-cost ratio of overall improvement was high as 7.03. It was non valuable investment in *define*, *measure*, *analyses* and the initial of *improve* stages after that it kept increasing. This was due to there were no benefits in *define, measure*, and *analyze* stages of six sigma since these three stages mainly determine the cause of problem and its effects rather than improve the process. The benefit-cost ratio starts existing in the improve stage and go on. Within each stage, the individual benefit-cost ratio was much higher than the accumulative one as there was an accumulation of cost since the first stage of six sigma. The consideration of the benefit-cost ratio during the improvement project helps make decisions for cost saving of similar activities during the improvement and for new project. In conclusion, the determination of benefit-cost ratio behavior through out six sigma implementation period provides the useful data for managing quality improvement for the optimal effectiveness. This is the additional outcome from the regular proceeding of six sigma.

***Keywords*—**Six Sigma Solutions, Process Improvement, Quality Management, Benefit Cost Ratio

I. Introduction

SIX Sigma solutions is a systematic quality improvement technique or a way to further enhance business performance [1]. It is a tool for quantitative managing of the organization [2]. It emphasizes the breakthrough improvement or the output based. Its objective is to discover the non value added activities hiding in working system. Even though there are a lot of effective tools used to improve and to reduce the loss in process but six sigma solutions is the most popular tool and it has been judged as the world class strategy for quality improvement [3]. The objectives of quality improvement project using six sigma could be the financial benefits increment, the operations performance increment, and the better the company image [1], [4]-[6]. The objective of project leads to how to evaluate the accomplishment of its improvement. The economic index would be determined if the project aims to increase the financial benefit [1], [3], [7]. The defective part per million (DPPM) or the amount of defect reduction will be focused for the project aiming to reduce the loss from defect or to increase the production yield [1], [7].

A benefit-cost ratio (B/C ratio) is one of indexes used to evaluate the accomplishment of the general project concerning with the financial consideration [8]-[10]. It attempts to summarize the overall value for money of a project. One majority of improvement projects can be selected based on cost minimization [6]. Most mature six sigma companies track their financial results that impact to management on a regular basis [7], [11]. Benefit and cost indexes can be used to select the quality improvement techniques, which mostly concerns at the initial and the final stages [3]. At the start, this index helps to select or is used to reveal the initial status of improved project [6], [12]. At the end, it helps to evaluate the return from the project improvement. In reality, quality improvement via six sigma solutions is time consuming project. It requires the additional investment or *cost* in each stage in order to achieve the anticipated *benefit*. Financial consideration is important and useful for managing the accomplishment of any project [8]. For six sigma, it is skeptics argued that it lacks discriminated validity over prior approaches to quality management [1]. In this case, the determination of the cost and benefit of each stage would raise the effective quality improvement. Therefore, the application of six sigma method together with the benefit and cost determination is interesting. There might be some limitation of the determination of benefit of the production industry as some benefits cannot be valued and some benefit usually accrues sometime after implementation of change [10]. In this case, this work will focus on the benefit from the reduction of non-conforming product. The case of interest is the tile-concrete manufacturing which is one of large enterprises in Thailand.

Manuscript received on July 29, 2011. This work was supported in part of the National Research University Project of Thailand, Office of Higher Education Commission, and the Faculty of Engineering, Thammsat University, THAILAND.

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II. THEORY AND METHODOLOGY

A. Six Sigma

Six sigma solutions is a method for process improvement. Its structured is patterned after PDCA cycle [2], [13]. Six sigma solutions consist of 5 stages. It is called as DMAIC methodology which is represent for *define* (D), *measure* (M), *analyze* (A), *improve* (I), and *control* (C) [6], [14], [15]. Each stage has it own purposes as shown in Table I.

TABLE I
SIX SIGMA APPROACHES [15], [16]

Stage	Steps
Define	Define projects Determine and prioritize customer needs and requirements Make a business case for the project Select one or more critical to quality (CTQ)
Measure	Determine operational definitions Validate measurement system Assess the current process capability Define objectives
Analyze	Identify potential influence factors Select the vital few influence factors Hypothesis test Conduct ANOVA
Improve	Quantify relationship between control factors and CTQs Design of experiments to modify the process or settings of influence factors in such a way that the CTQs are optimized Conduct pilot test of improvement actions
Control	Determine the new process capability Implement control plans

There are a numbers of tools which can be applied individually or together in each stage of six sigma for diagnosis the problem and its cause such as the design of experiment, statistical process control, failure mode and effect analyses and etc,.[5], [6] [16].

From the statistical point of view, term of six sigma is defined as having less than 3.4 defects per million opportunities or success rate of 99.9997% [7], [16]. The case of interest operates less than one year. It also has some limitation from raw materials. Their properties depend on their sourcing area which is uncontrollable. As one of key factors for implementing a successful six sigma program is the project has to be feasible [7]. The achievement of six sigma is also effected by the production age [2]. Therefore, this research will not attempt to hit the six sigma target. The production of interest will be improved following the six sigma solutions so that it will have the performance the same as the company targets and the customer required. Firstly, the project of interest will be selected as well as the customer needs and the critical to quality will be specified in *define* stage. After that the process capability of the production of interest will be measured. In this case, the objective of an improvement can be set in *measure* stage. Then, some experiments will be performed to scope the potential causes and to identify their influence parameters in *analyze* stage. The design of experiment will be used in the *improve* stage to determine the suitable condition for improving the process. In the final stage, the process will have been maintained and *controlled* according to the suitable condition found in the improved stage. The improved condition such as the process capability, defect rate and production yield will also be measured.

B. Benefit Cost Ratio

Benefit is value of resources produced or saved as the result of the implementation of project measured in the same unit as the cost (typically money) [9]. *Cost* is the value (typically monetary) of the amount of different types of resources consumed to implement the project. Benefit cost ratio arranges the discounted benefits (B) and costs (C) as a ratio rather than as a difference. The rule is $\frac{B}{C} \geq 1.0$ [17].

This improvement mainly focuses on the production. Therefore, the benefit of interest for this work will be the benefit from the reduction of non conforming product only. As the units of benefit and cost should be the same [9] so the index of non conforming product will be calculated from unit price which is calculated from the factorial cost [10]. The opportunity cost is neglect in this case as the project life is shorter than 1 year and the additional investment is not high as well as the interest rate is very low now.

III. SIX SIGMA PROCEDURE AND RESULTS

This section presents the procedures of quality improvement and their results referring to the five stages of six sigma.

A. Define Stage

This stage aims to scope and plan the work. It is very important to clarify the problem and to specify what is the critical to quality of the product of interest. From the production data, it was found that the yield of production of interest has been quite low, 70% approximately. The product of interest is the tile-concrete. Based on its usage, the critical to qualities include the physical and the mechanical qualities. This case applied the quality function deployment (QFD) as it is the technique that incorporates the customer requirements and performs competitive evaluation to identify the design requirement [6], [18]. The result was summarized in Table II. It reveals that the most critical to quality for customer is strength which is a mechanical quality of tile-concrete.

TABLE II
SUMMATION OF % WEIGHT OF QAULITY OF TILE ANALYZED BY QFD

Quality	%Weight
neat surface	8
Strength	31
weight/area	5
coating	24
joint distance	16
easy to install	7
alignment after install	9
Total	100

Physical quality concerns with the tile appearance such as color or surface finished. Further collection of data, there were a lot of defects from the surface appearance shown in Fig.1 such as scratch, color, surface coating, etc,. Fig.1 also shows that the most potential defect is surface coating. It is the second critical to quality to customer after the strength (Table

II).

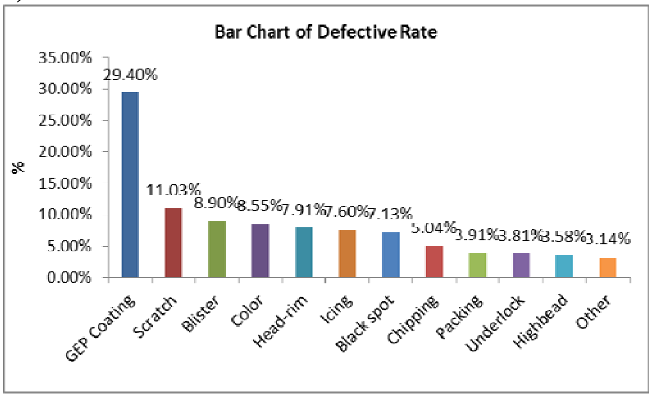
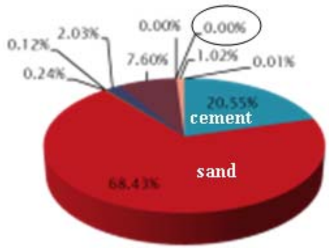
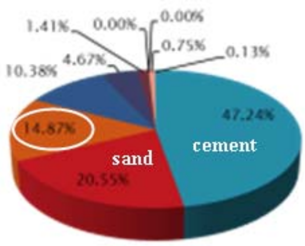


Fig. 1 Non conforming defect in tile-concrete production

All non conforming products, low strength and poor surface, will be destroyed as they cannot be repaired. Therefore, there will be a big loss of material cost. Two main materials of tile are cement and sand. The rest are various such as coating agent, additive agent, or dust stone. If the amount of materials is considered, the amount of coating agent loss is very small (<0.01%) as in Fig. 2(a) but if the cost is considered, the cost of coating agent (14.8%) is the first three highest costs of materials after cement and sand as in Fig. 2(b).



(a)



(b)

Fig.2 Comparison of material ratio based on (a) amount and (b) cost

If the defect rate based on the strength of tile-concrete is determined, this quality may not be important. But it is very important quality based on the usage of the product and it is the first quality required by customer. Even though the defect rate from strength is very low but the capability of process based on this quality is quite low too. This means that there is a lot of chance that this quality will be out of specification. Therefore, it is very important to increase its process capability.

In this case, this stage of six sigma *defines* that the surface coating and the strength are critical to qualities of tile product.

B. Measure Stage

This stage aims to determine the current status of the critical to tile quality. The defect rate and the process capability will be *measured*. There are two critical to qualities as defined in the former stage. Therefore, the outcome of this stage will be divided based on the types of critical to qualities of tile-concrete which are surface coating and strength.

1. *Surface coating*

The problem is poor surface coating which has various types. It was found that the highest percentage type of this defect is faded coating color (blightless). It took 69% of the amount of defect from poor surface coating as shown in Fig. 3.

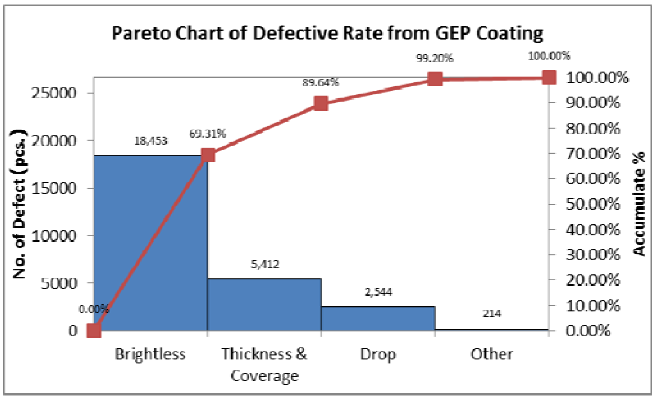


Fig. 3 Type of poor surface coating

The determination of process capability of surface coating found that it was very low as Cpk and Ppk equal to 0.36 and 0.39, respectively, as shown in Fig. 4.

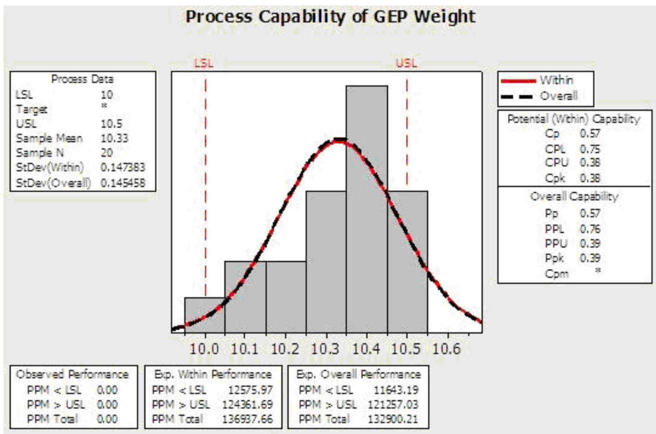


Fig. 4 Process capability of coating process (before improvement)

2. *Strength*

The problem here is low capability of process. It was found that Cpk and Ppk are 1 and 0.87, respectively, as shown in Fig. 5. There is a lot of variation of strength value. Even though their values are higher than lower specification limit but lots of them have much higher strength than required. In view point of customer, the quality is fine but the process capability should be improved. In the view point of the manufacture, the higher the strength, the larger the production cost will be.

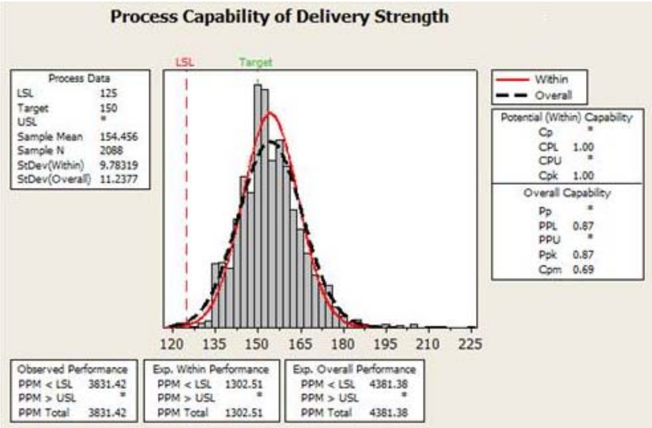


Fig. 5 Process capability based on strength quality (before improvement)

In this stage of six sigma, the current statuses of problem of interest were *measured*. It was suggested that improvement projects should be selected based on improving customer satisfaction and operational efficiency [6], [19]. In this case, this research will set the objectives for this improvement based on the defined critical to qualities. Therefore, the main objectives are (1) to reduce the defect rate and to increase the process capability of surface coating process and (2) to increase the process capability based on the strength quality. By doing these, the production yield could be increased. Furthermore, one more benefit which is the reduction of materials loss would also be achieved.

C. Analyze Stage

This stage aims to identify the influence parameter affecting to the cause of the problem. The same as in the *measure* stage the *analyses* will be divided based on the surface coating and the strength of tile-concrete.

1. *Surface Coating*

The problem is faded coating color. The coated surface of interest was deeply inspected and it was noticed that the color of most of faded tiles was gradually faded from one end to the other end. The difference the weight of coating agent, the difference the color reflection will be. In this case, some tests were performed to analyses the cause of the problem with the hypothesis that the weight of coating agent was uneven. Tile surface was divided into three regions as shown in Fig. 6.

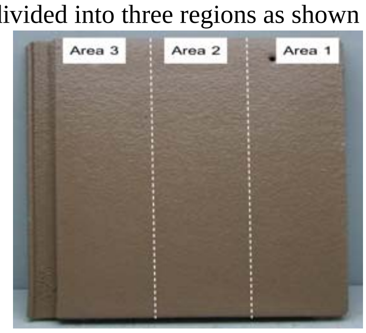


Fig. 6 Regions of weight of coating agent determination

The measurement of the weight of coating agent was done and it was found that the gradually faded color was due to an uneven coating as shown in Fig. 7. Comparing the weight or the amount of coating agent among three regions found that the weight of coating agent was highest in area 1 and lightest in area 3. There was also the variation of the weight within each region. This results in the difference of color shade throughout the tile. That is why it seems to be faded in some area when it is reflected to the light.

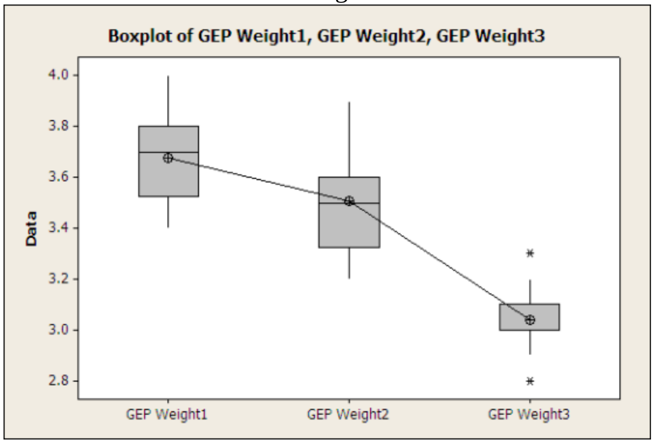


Fig. 7 Weight of coating agent throughout tile surface

Process mapping helps to identify input and output of process and process parameter [6], [20]. By mapping the processes, It was found that the most potential cause affecting to the poor coating problem was from the coating system concerning with the various parameters. In this case, the potential parameters affecting to the coating system were also determined. Four possible parameters were proposed including the size of muffler, the machine stopping time, the temperature of nozzle, and the temperature of agent tank.

2. *Strength*

The strength of tile-concrete is dependent on its composition. As sand and cement are the main materials for this product; therefore, the preliminary determination of sand and cement ratio (S/C) was conducted to determine the most valuable composition. The prestige strength was measured and plotted via S/C ratio as in Fig. 8.

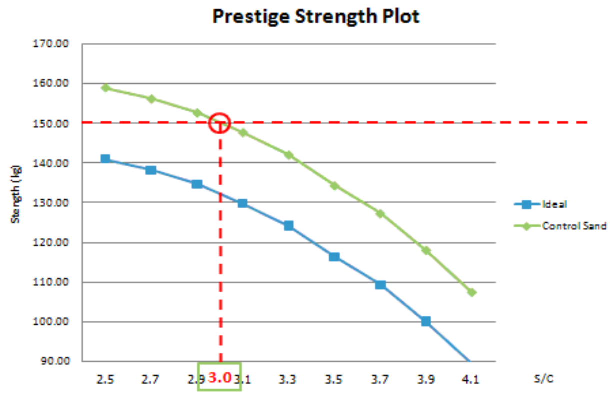


Fig. 8 Valuable S/C ratio determination

The production target of strength level is 150 kgf which can be achieved when the composition between sand and concrete is lower than 3.0. From Fig. 8, the lower the S/C ratio, the better the strength will be. Lower ratio means larger amount of cement or smaller amount of sand. From Fig. 2, the cement is more expensive than the sand. Therefore, the most valuable composition of S/C should be set at 3:1.

This research also aims to increase the process capability base on the strength quality. In this case, it is necessary to determine the additional potential parameters that could affect to the strength of tile-concrete. From process mapping, there were 7 possible parameters including tile weight, tile thickness, the amount of cement, the amount of sand, the amount of additive agent (RD1), the ratio of RD1 to cement, and the compression of tile.

Conclusion for this stage, the root cause of both two improvements was *analyzed*. The possible parameters affected to poor coating surface and low process capability based on the strength quality were determined.

D. Improve Stage

This stage will continue what are found from the analyses stage. Further experiments will be performed to determine the suitable condition so that the suitable improved method can be conducted. As *measure* and *analyze* stages, the improvement will also be divided based on the surface coating and the strength of roof-concrete.

1. Surface Coating

There were four possible parameters of interest. In this case, 2^4 Factorial Design was applied to determine the potential parameters. The experimental data showed that the size of muffler and the machine stopping time (SMDT) significantly affected to the problem of uneven coating. The possible levels of these two parameters were also selected from the main effect plot in Fig. 9. It was found that the process should be better (the difference of color shade is smaller) when the stopping time is one minute and the big size of muffler is used.

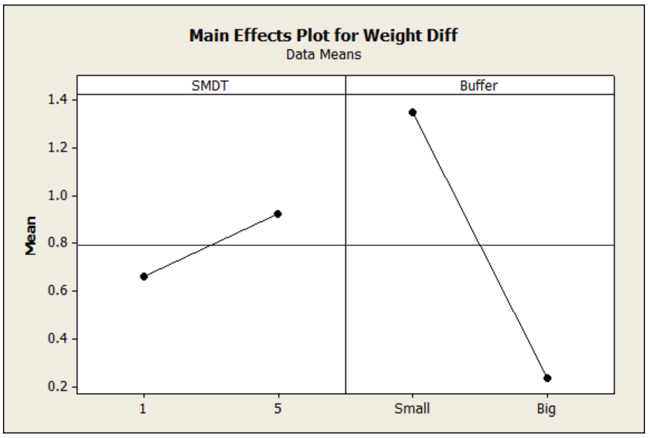


Fig. 9 Main effect plot of parameters affecting to surface coating

Further investigation was performed by response optimizer to determine the suitable machine stopping time for least difference of color. It was found that the stopping time should not be longer than 3 minutes in order to achieve a least difference of color shade as shown in Fig.10. It is also confirmed that the suitable size of muffler should be the big one.

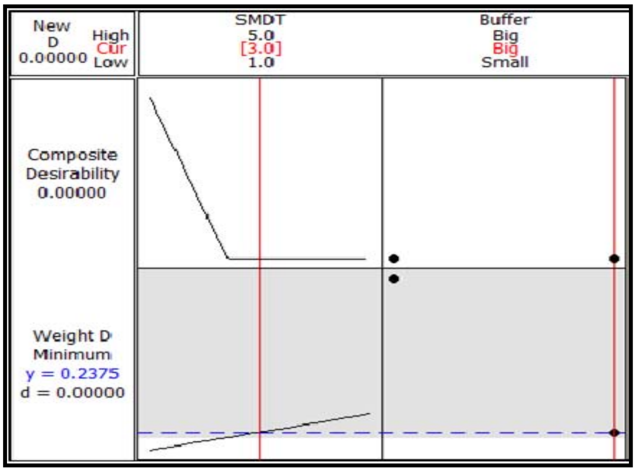


Fig. 10 Suitable level analyzed by response optimizer for coating system

2. Strength

There were eight parameters proposed to affect the strength quality of tile. The factorial experimental design requires a lot of numbers of experiment. There was also the reason from benefit-cost ratio consideration (discussed in section IV). The historical data were pre-analyzed by multiple regression analyses in this case. It was found that the potential parameters are tile weight, cement, sand, and S/C ratio. Their effects were shown in Fig. 11. It reveals that the weight of the product has a big impact on strength.

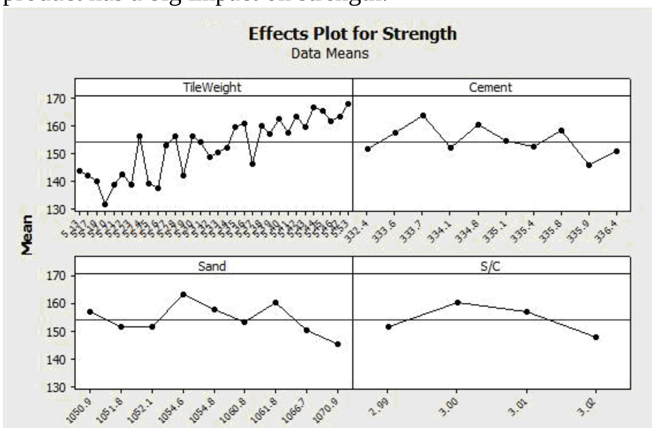


Fig. 11 Effect plots of parameters affecting to strength

Further analyses by response optimizer found the suitable level of each parameter for achieving the strength target as shown in Fig. 12. From the result the suitable weight is 5.2 kg. The suitable amount of cement and sand are 334 and 1057 kg, respectively, which provide the S/C ratio at 3:1 as found in preliminary test (Fig. 8).

Further improvement was also conducted by determining the additional improvement rather than technical improvement. Some mechanical control was adopted to control the pressure and the dispersion of laminating agent during spraying. The maintenance system was also reorganized for providing the efficient and the effective service.

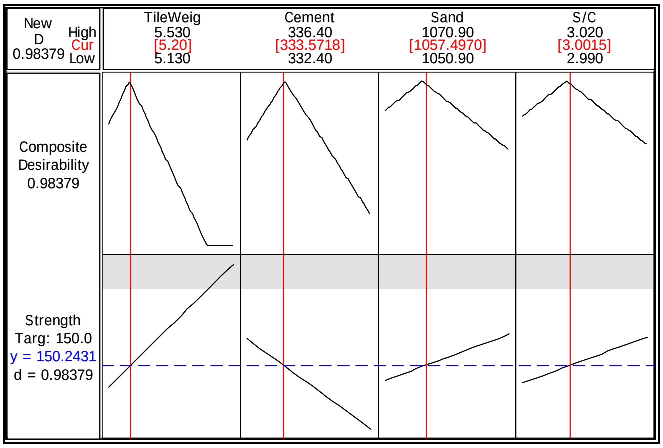


Fig. 12 Suitable level analyses by response optimizer for required strength

E. Control Stage

From *improve* stage, the suitable parameters affecting to the critical to quality of tile were already found. To achieve the better coating on the surface, the process should use the big size of muffler and should set the machine stopping time not longer than 3 minutes. To achieve better process capability of the strength quality, the weight of the tile should be 5.2 kg. The amount of cement and sand should be 334 and 1057 kg at which its ratio is 3:1. This ratio also provides the most valuable composition. These conditions were used to operate and control the production to achieve the objective of the improvement. It is very important to maintain the improved system to prevent a recurrent of the problem. The continuous monitoring of the process has been performed. By monitoring for six consecutively months since *improve* to *control* stages it was found that the case of interest was able to reduce the defect rate of surface coating from 29.4% to 4.09%. The production yield was increased from 70% to 80% (company target). The process capability based on the coating process was improved to 0.65 for Cpk and 0.65 for Ppk as in Fig 13. Furthermore, the Pp was also improved from 0.54 to 1.02.

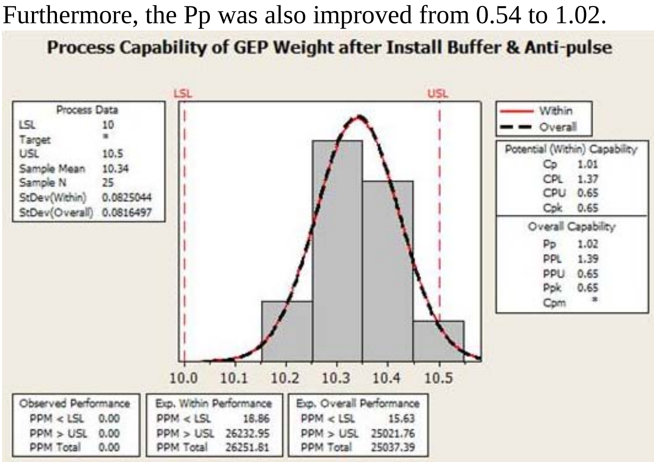


Fig. 13 Process capability of coating process (after improvement)

The process capability based on the required strength was increased to 1.11 for Cpk and 1.08 for Ppk as in Fig. 14. Based on the manufacturing point of views, this project is successful [7].

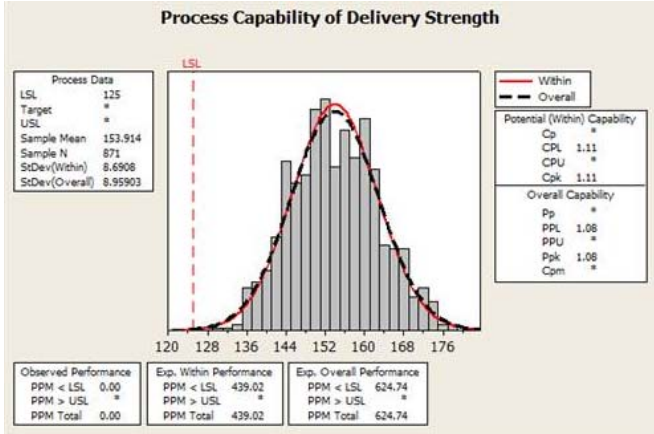


Fig. 14 Process capability based on strength quality (after improvement)

IV. Benefit and Cost Ratio Analyses

The benefits of six sigma project can be presented in financial returns by linking process improvement with the cost saving [7]. This case aims to reduce the defect rate and also to increase the number of tile having strength closer to the target. Therefore, the benefit will be determined from the reduction of the number of problem tiles which is transferred in the unit of money by its unit production price [10].

By following the six sigma solutions, the case of interest can not only reduce the defect rate and increase the production yield but it can also reduce the production cost for 3.24 million bath or 0.11 million dollars. The average benefit cost ratio of each stage throughout the Six Sigma implementing is shown in Fig. 15.

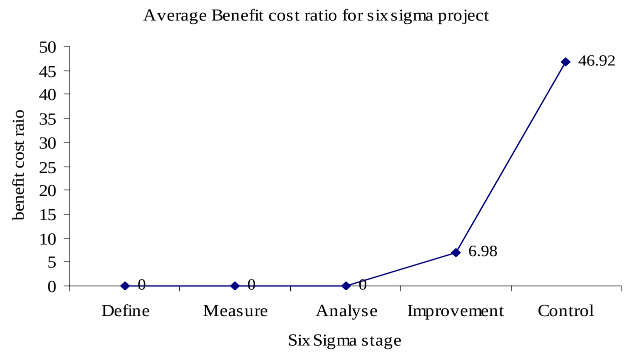


Fig. 15 Benefit-cost ratio of five stages of six sigma solutions

If the evaluation is based on the benefit-cost ratio, the benefit-cost ratio of this project is 7.03 after completion of the project as the total benefit and total cost are 3.24 and 0.46 million baht, respectively. In this case, this is a valuable investment [17]. As the Six Sigma is time consuming project; therefore, the cost and benefit are accumulated from the start till the end. In this case, the accumulative benefit and accumulative cost ratio can be plotted in Fig. 16.

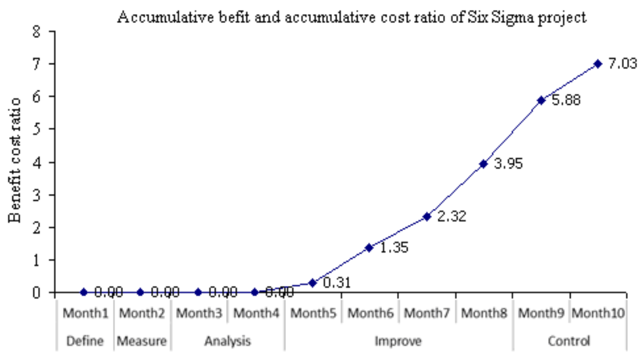


Fig. 16 Accumulative benefit and accumulative cost ratio of six sigma project

The return from the improvement can be deeply determined in detail if the cost and benefit-cost ratio versus time are constructed. By doing this, the project can be evaluated periodically throughout the project implementation. The benefit-cost ratio and the cost plotted throughout 10 months of quality improvement project by six sigma was constructed as shown in Fig. 17.

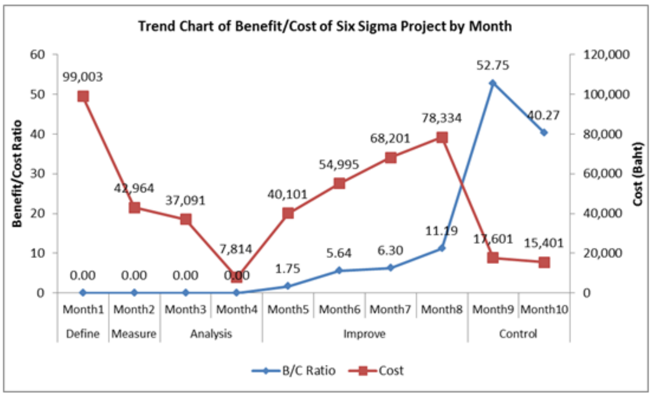


Fig. 17 Cost and Benefit-cost ratio of Six Sigma Project

V. Discussion

Individual determination of improving cost found that there was a cost since the start of the project. This is the general manner for project setting or improving [21]. The *define* stage also includes the preparing of improvement group and facility [13], [21]. For this case, it was mainly from labor cost of working teams. At the start, a multidisciplinary team was formed from various groups of staff as a cross-functional team is necessary to provide an involvement of implementing process [6]. After that the number of staff was down as the work was scoped more and more from *measure* to *analyze* stages since the objective was clearly defined and the improvement direction could be narrowed. The concerned people were clearly specified. The cost was gradually increased again throughout the *improve* stage as there were a lot of experiments done. During the improvement, the nonconforming defect was gradually reduced. This was when the benefit of the improvement could be detected as this work has scoped the benefit determination from the reduction of the number of nonconforming. As process has been improved to the controlled stage, some activity could be reduced [23], [24]. For this improvement, once all suitable conditions found at the end of the improve stage, the cost was remarkably dropped and remained for process monitoring confirming to the control issue.

From Fig. 16, the benefit-cost ratio up to month 5 had not been valuable. It had been zero for first four month as there had been no benefit from the defect reduction. There was benefit-cost ratio in month 5 but it was not valuable. This was due to there was an accumulation of cost from the start of project. On the other hand, it was valuable when considering within its own period (Fig. 17). If the benefit cost ratio has not been high as target required, the improvement could be proposed by considering the stage that has very high investment such as in *define* or in *measure* stages (Fig. 17).

For individual improvement, the accumulative benefit-cost ratios for surface coating and for strength were shown in Fig. 18 and Fig. 19, respectively. It was found that the benefit starts exiting in the *improve* stage as the defect rate starts being reduced. From Fig.19, the improvement of strength quality project was not performed in month 5 to month 7. All of improvements were launched for surface coating only. But in the same manner both improvement start providing the benefit since the improve stage.

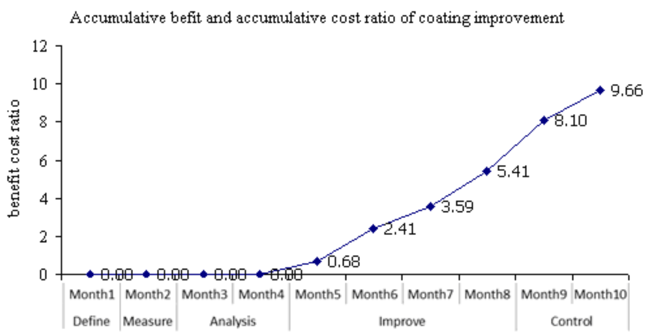


Fig. 18 Accumulative befit and accumulated cost ratio of coating improvement

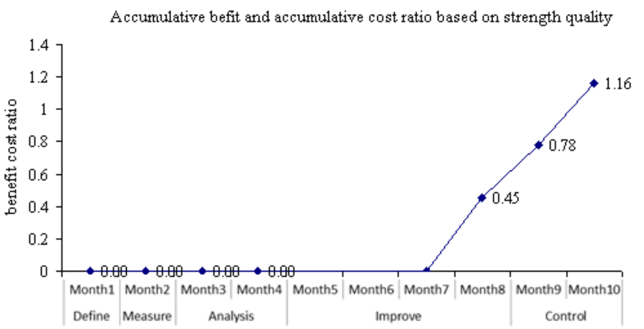


Fig. 19 Accumulative befit and accumulated cost ratio based on strength

If the benefit-cost ratio is determined in each stage, the results of both cases were individually plotted as in Fig. 20 and Fig. 21. In this case, it was found that the improvement of surface coating provide more impact than the process capability improvement based on strength quality even though it is the most important quality for customer need. But the strength project was also valuable and successful as customer oriented.

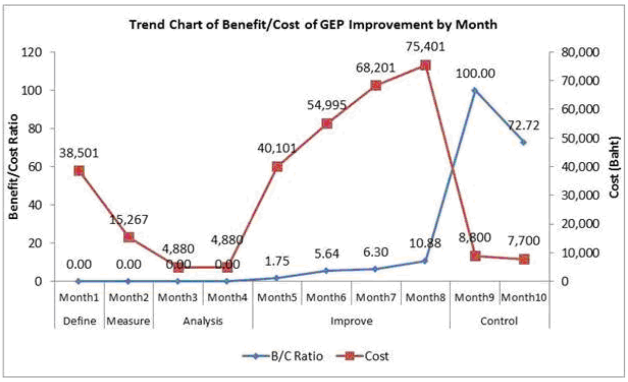


Fig. 20 Benefit Cost ratio for surface coating improvement

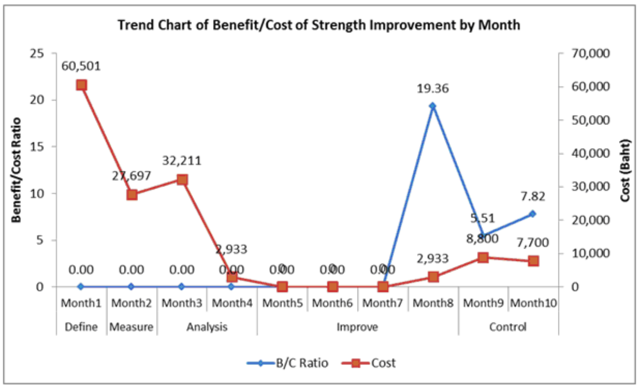


Fig. 21 Benefit Cost ratio for improvement of strength capability

The surface coating improvement had higher benefit-cost ratio than overall project since there was higher additional investment in process capability of strength improvement than the surface coating improvement. This was from a poor planning since the case study believed that the strength project was more difficult and need more process specialist than the coating project. This should be a caution for the next improvement. The investment within *improve* stage is valuable for both cases but the surface coating improvement gives more benefit-cost ratio or have more valuable investment than the process capability improvement. This might be due to lower defect based on strength quality than surface coating at the initial; therefore, the return is low as the benefit is calculated from the unit price of reduced defect. For the strength case, it is established to satisfy the customer needs. It will affect to the trust of customers. They might increase an order number which would be a big benefit and provide higher benefit-cost ratio later.

During the *improve* stage, the cost of surface coating improvement is higher than that of process capability of strength. Once the *improve* stage started, the improvement was only performed and continued for surface coating. From the data of the cost spent in this stage, it was high from the 2^4 factorial design of experiment as there were 4 parameters affecting to surface coating. For strength quality, there were 8 parameters. Since they were all quantitative parameter; therefore, their historical data were mainly used to save the cost from the experiment. The improvement of process capability based on the strength was started again in month 8 after it had been stopped in month 5 to month 7. By considering the cost and benefit-cost ratio of similar activity during the six sigma project, some decisions on the other project can be made as the project of process capability improvement based on the strength could save more cost than surface coating project. Consequently, overall benefit-cost ratio of six sigma is increased.

First three stages of Six Sigma mainly determine the causes of problem and its effects rather than improving the problem so the benefit in term of the reduction of problem will not be found. In reality, there may be the benefit in term of the expertise of employees which is normally subjective and indirect to the improvement. It is a qualitative term unless the company has a good data for training cost the benefit might be evaluated [10]. The last two stages of six sigma mainly try to determine the better conditions. The improvement resumes so the benefit starts existing. Therefore, the benefit cost ratio is quantitatively determined. But there will be an additional investment in each stage of six sigma project. The determination of individual cost and benefit-cost ratio in each stage is also suggested. It could provide the useful data for project preparing or project evaluation or project managing of overall and/or of each stage of six sigma projects for the continuous improvement or the new project.

ACKNOWLEDGMENT

This work was supported by the National Research University Project of Thailand, Office of Higher Education Commission. There was also an academic support by Faculty of Engineering, Thammasat University.

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