Application DMADV together with Quality Function Deployment in the development of self-driving vehicles AGV

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Abstract. This research aimed to reduce wasted time in delivering specimens through Thailand's healthcare industry using the Six Sigma methodology. Six Sigma consisted of five phases: defining, measuring, analyzing, improving, and controlling. In conjunction with quality tools and Failure Mode and Effects Analysis FMEA, which discovers potential causes of failures within the process; Risk Priority Number RPN was considered to identify causes associated with failures. The research was conducted in the Clinical Laboratory Section of Srinagarind Hospital. The average walking distance to deliver specimens was 416 meters/round. The average time spent walking to deliver specimens was 3.14 minutes/round. After improvements were made, it was found that the wasted time in transporting specimens decreased by 95%. In addition, on average, an automated guided vehicle AGV improved staff performance by 90%.

Keywords: Six Sigma (DMADV), Quality Function Deployment (QFD), Automated Guided Vehicle (AGV)

1. Introduction

Open innovation is a hot issue for firms that wish to stay up to date. The utilization of smart service systems in hospitals will provide significant assistance for patients. These systems include personal health records, medical equipment, and smart devices to store data. Also, provide directives, such as automatic medication dispensers, medicine notifications (personal digital device assistance), computer-aided diagnosis systems meeting international standards, such as mammogram analysis systems, accounting systems, and electronic inventory. It includes research and development for service-aided robots to care for patients and robotic surgery technology to produce more effective and efficient surgery procedures and results. Robotic surgery is beneficial in areas of limited space and diminishes blood loss because of its improved precision. In addition, patients will experience less pain than traditional surgery, which is more problematic and has a higher risk for complications.

A model hospital is established to offer a combination of traditional Thai medicine and conventional medicine and promote applications of traditional Thai medicine in a broader range of treatments. Every hospital should have a healing environment that improves healthcare efficiency and contributes to a pleasant hospital atmosphere. The hospital administration should provide skill development activities for healthcare providers. Executives should participate in the Global Health Leadership Program, whereas experts in the Department of Medical Services DMS should participate in World Authority and Highly Specialized Training to achieve higher productivity growth. DMS Medical Complex is developed into a public organization to ensure more effective management.

However, in developing countries, a significant number of improvements are required, especially in terms of research and medical equipment. Based on the examination of secondary data from research reports, articles, industrial classification standards, policies related to the health industry, associations with industrial networks, and interviews with experts and relevant individuals, there are many networks supporting operations within the medical profession [1]. This is based upon findings from the United Nations' International Standard Industry Classification of All Economic Activities (ISIC, Rev.4).

According to Thailand 4.0 policy, in conjunction with selecting healthcare technology with the potential to drive Thailand's healthcare industry toward a competitive global level, the focus should be placed on advanced medicine. An analysis of Thailand's

healthcare potential in the medical industry is based upon positive production factors, including healthcare providers, raw materials, drugs, and medical supplies. On the other hand, a negative factor related to production is excessive reliance on advanced health technology from abroad. Therefore, to develop the potential for the healthcare industry to drive the country forward, it is essential to accelerate the development of advanced healthcare technology to reduce Thailand's reliance on foreign technology. In addition, since Thailand is a medical hub with increasing numbers of foreign customers, this is another factor encouraging the development of advanced health technology.

According to an analysis of intelligent property of Thailand's medical industry, factors to be taken into consideration when choosing potential technology include:

1. Connection between industry classification and networks supporting the medical industry;

2. Factors of production in the medical industry that Thailand has and what Thailand lacks or requires dependence on other countries related to foreign technology; and

3. A trend toward adopting technology that conforms with Thailand 4.0 to drive Thailand's medical industry to a new advanced industry (New S-Curve).

Thus, the objective of this research study seeks to identify and reduce defects in specimen delivery processes within Thailand's healthcare industry by using the Six Sigma approach to improve work processes, increase personnel performance, and reduce steps in the specimen delivery process by foot at the Clinical Laboratory Section of Srinagar Hospital. Furthermore, examining factors related to deficits involved in specimen delivery and medical development suggests the expediency for Thailand's medical industry to focus on research and development of automated guided vehicles or medical robots to improve patient satisfaction.

2. Related Literature for Six Sigma DMADV

The Six Sigma approach uses statistical methods to enable organizations to earn more profits and generate more products that can be applied to products and services. The Greek letter sigma is used in statistical analyses to mean the standard deviation of a quantity. Six Sigma measures average variances deviating from the standard mean, with a higher Six Sigma value representing higher quality. To statistically achieve a Six Sigma level of quality, the organization under examination is only allowed 3.4 parts per million PPM defective [2].

2.1. Six Sigma

The Six Sigma approach is a management system not only focusing on generating less than 3.4 defects per million opportunity, but also consists of major phases to ensure successful management. Such phases include defining, measuring, analyzing, improving and controlling. In each phase, quality tools can be used to help analyze and identify causes of defects. These tools include check sheets, graphs, Pareto charts, cause and effect diagrams.

2.2. DMADV

The DMADV approach is the most used in the field of Design for Six Sigma and is the one that will be used for our analysis [3]. As previously mentioned, this approach consists of 5 distinct phases: Define, Measure, Analyze, Design, and Validate. Each phase has its own objective; at the end of the last phase it will have come to a design in line with the Design for Six Sigma methodology [4].

1. Define. During the first phase, the client's requests and needs on information is collected. Specifically, it is important to note what problems the customer encounters when approaching a specific product already on the market.

2. Measure. In this phase the Quality Function Deployment analysis is carried out to translate the customer's needs into engineering information. In this way it is possible to obtain those characteristics linked to the design that influence the respect or not of the customer's requests.

3. Analyze. The key features obtained in the second phase are used to conceive the design of the new product. For this purpose, a benchmarking analysis is carried out, which allows to study similar designs of competitive models with the product in question.

4. Design. Depending on the results obtained from the analysis phase, we proceed with the design using appropriate software of the new product. In this phase, all the information obtained from the previous points must be taken into consideration and attempts must be made to respect them to the best.

5. Validate. In this last phase, it is stated with certainty that the finished product confirms the expected results. It is possible to produce prototypes to be tested to ensure that the product is in line with the required characteristics.

All could be clearer through the image (Figure 1) below:

Fig. 1. Research Methodology

Moreover, Failure Mode and Effect Analyze Process (FMEA) were used in combination with the Six Sigma approach to determine causes of defects in the manufacturing process, accounting for severity, occurrence, and detection to prioritize the potential causes of defects. Risk Priority Number (RPN) was performed to rate such potential causes according to severity of the potential effect of the defect (severity), likelihood that the defect will occur (occurrence), and ability to detect such defect (detection). After that, the cause with the highest RPN value will be corrected first since it has the highest impact [5].

Quality Function Deployment is a model pioneered in Japan in the 1960's by Prof. Dr. Yoji Akao. According to American Supplier Institute ASI, QFD is defined as a system that aids in translating customer needs into goals that are suitable for an organization in every process from research, design and development of a product to manufacturing, installation, marketing, distribution and services. It can be concluded from such definition that QFD is based on translation of customer needs. [6].

3. Research Methodology

The research procedure and methodology were determined based on a review of related literature. The problem could be solved by the Six Sigma approach consisting of five phases: Define, Measure, Analyze, Improve, and Control, as shown in Table 1. [6]. This phase involves collecting information regarding the client's requests and needs. More specifically, it is necessary to obtain data on which to rely in order to understand what the product requirements must be. To this end, using the QFD as a tool for clarifying the task is useful. This method lends itself to planning each phase and, therefore, can be used at various levels. The method starts with correctly identifying product needs, an easily obtainable objective, and interviewing a limited number of people. The questions to be answered are the following [7].

Table 1. QFD-Six Questions.

Quality Function Deployment	Personnel's Needs
Functionality	- Being able to move quickly - Being able to stop at required positions -Being able to function for long consecutive periods
Design Art	-Robust structure - Suitable for intended use - Modern form
Materials	- Strong and robust - Not expensive - Available in local market
Safety	- Work safety - Personal protective equipment - Easy maintenance
Convenience	- Ease of movement - Ease of cleaning - Ease of installation

4. Results

4.1. Defining Phase

From observations of personnel in the Clinical Laboratory Section of Srinagar Hospital, the average walking distance to deliver specimens was 416 meters/round, and the average time wasted walking to deliver the specimens was 3.14 minutes/round. On average, each day, there were 4,300 specimens delivered. Five personnel were employed to deliver specimens to different laboratories. The average distance each of the personnel walked was 13 km/day. Thus, this study was conducted to reduce the time wasted during the delivery process of specimens in Thailand's healthcare industry by using the Six Sigma approach within the Clinical Laboratory Section [8].

To analyze personnel's work posture in delivering specimens in the Clinical Laboratory Section, the Pareto Chart (cause and effect diagram) shown in Fig. 2 describes defects detected when personnel delivered specimens. The walking distance to and from the Clinical microbiology Unit was the longest and took the longest time. Therefore, this research chose to reduce time wasted walking to deliver specimens in Thailand's healthcare industry using the Six Sigma DMAIC methodology [9].
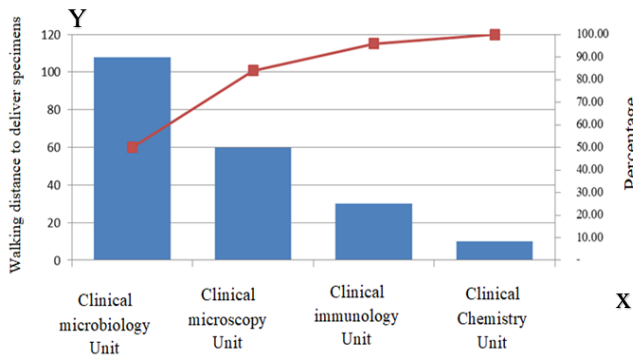
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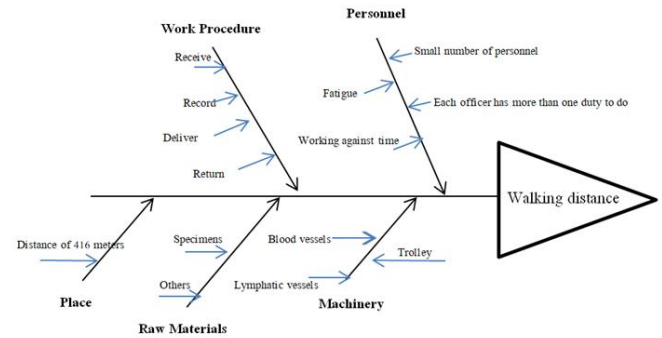**Fig. 2**. Pareto Chart of Defects in Specimens Delivery.

Fig. 3. Diagram showing the walking distance.

4.2. Measuring Phase

After carefully examining the process, the cause and effect diagram was used to determine the causes of defects. Finally, a brainstorming session was conducted and attended by relevant experts to identify all inputs potentially resulting in such defects, as shown in Fig. 3 below.

Potential causes of problems with walking distances to deliver specimens can be divided into four categories: personnel, machinery, work procedures, and raw materials. Potential causes associated with personnel were work procedures, which required an officer to receive specimens from a physician, and then record a patient's history. After that, the same officer had to walk to deliver specimens independently for an average distance of 416 meters/round, which took him 3.14 minutes/round.

Much time was wasted walking to deliver specimens. If the officer spent the time used to deliver specimens on other tasks, he would be able to increase his unit's performance.

4.3. Analyzing Phase

An analysis of potential causes of defect mentioned above led to an analysis of the effect of such defect in the Failure Mode and Effect Analyze Process FMEA process. The FMEA is a study and analysis of the severity of each defect that affects the process by considering the Risk Priority Number RPN derived from the calculation of severity, occurrence, and detection. However, only those potential causes not cut off from the cause-and-effect diagram were considered as described above. After that, the remaining causes were
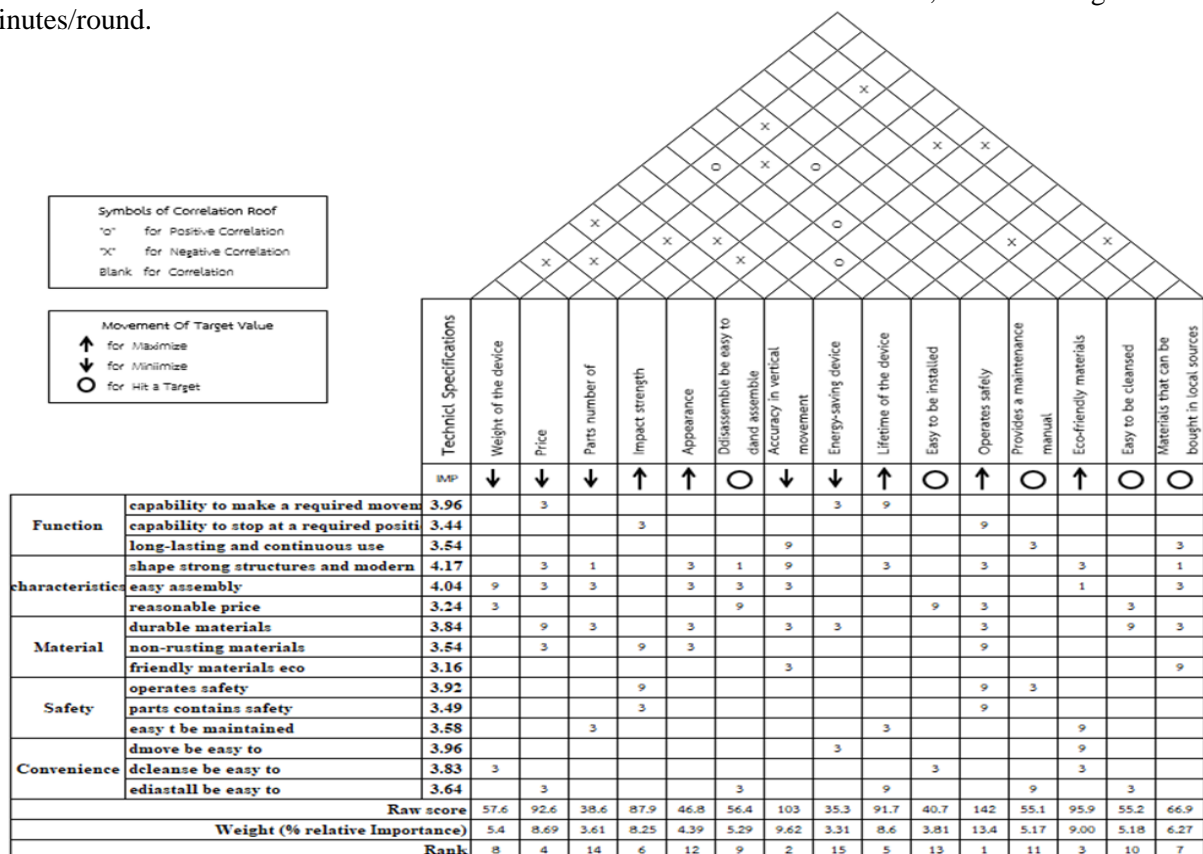

Fig. 4. The Example of Matrixes Used for QFD.

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User Requirements		Mean (IMP)
		Result Calculation
Function	1. accuracy	4.75
	2. includes a collision avoidance system	4.31
	3. includes a flexible system	4.44
Materials	1. eco-friendly and strong	4.38
	2. easy to be bought in local sources	4.44
	3. not get dirty easily and not rust	4.25
Characteristics	1. strong structures	4.56
	2. easy assembly	4.44
	3. proper size	3.94
Safety	1. operates safely	4.44
	2. contains an electrical leakage protector	4.31
	3. contains qualified device controllers	4.25
Convenience	1. easy to be cleansed	4.38
	2. easy to be maintained	4.19
	3. able to be moved easily	4.56

Fig. 6. The Mean (IMP) and the User Needs.

device users. The margin of error amounted to 0.05. The calculation was shown in (1) [10].

$$n = \frac{337}{1+337(0.05)^2} \qquad = 183 \qquad (1)$$

$$248 = \frac{337}{1+337(e)^2} ; e \qquad = 183 \qquad (2)$$

The result demonstrated that the number of the returned questionnaire had to be at least 183 to represent all samples at the Blood Transfusion Centre. In the study, 248 questionnaires were returned; this number was more than the minimum possible sample size. After that, the reliability of the returned questionnaire was calculated as shown in Formula 2 [10].

The result indicated that the reliability of the returned questionnaire was 0.968. Therefore, the data from these questionnaires could be used to measure the importance ratings. In addition, the margin of error was 0.032.

4.3.1. The Calculation Result of the Importance Ratings of User Needs.

The data of the returned questionnaires were used to analyze the reliability via Cronbach's alpha. From the calculation result, the reliability of the returned questionnaires was 0.957. This meant that the margin of error was low. Therefore, this data was used to calculate the importance ratings based on the geometric mean. The result was shown in Fig. 6.

Furthermore, the user needs and the importance ratings will be used to analyze the Planning Matrix of the QFDE technique.

4.3.2. The Results of the Application of QFDE.

The result from the QFDE technique consisted of 2 parts: the Planning Matrix and the Part Deployment Matrix.
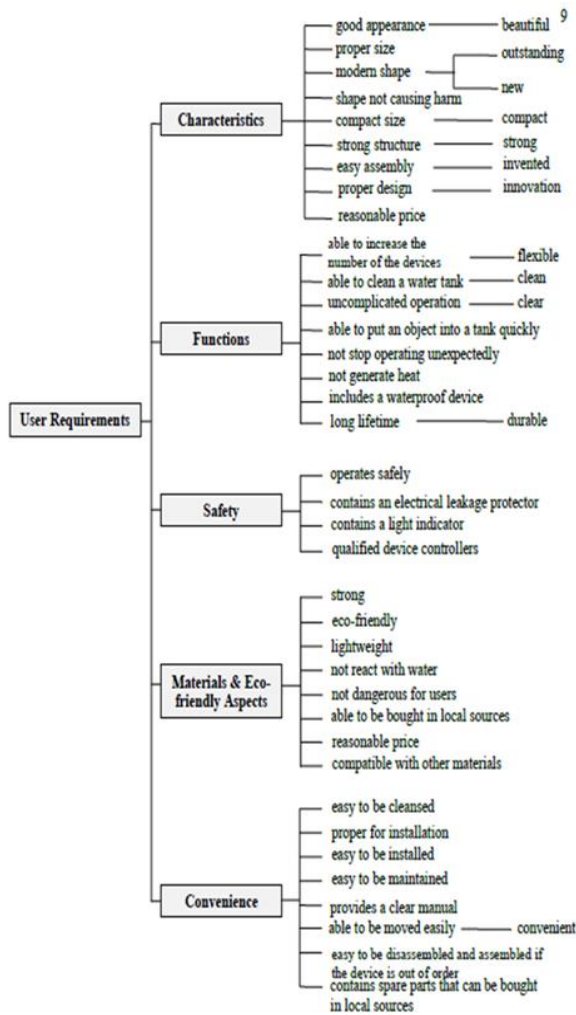

Fig. 5. The Tree Diagram of the Device Specifications Based on User Needs Example of Matrixes Used for QFD.

analyzed for impacts in order to determine the RPN and analyze the causes affecting the defect, as shown in Pareto Chart below, to select the cause with the most severe effect for the further problem-solving process, as shown in Fig. 4 and Fig. 6.

After that, all user needs were used to create the questionnaires to find the importance ratings for each requirement. The analysis of the questionnaires showed that the users could comprehend questions in the questionnaires. As a result, the researcher sent 337 questionnaires to the nurses, the nursing assistants, the staff, and the experts in medical equipment at the Blood Transfusion Centre.

According to the calculation of the sample size, the result demonstrates that the number of the returned questionnaire has to be at least 183 to represent all samples at the Blood Transfusion Centre. In the study, 248 questionnaires were returned; this number was more than the minimum possible sample size, indicating that the minimum possible sample size was 183 from 337

Movement Of Target Value
↑ for Maximize
↓ for Minimize
O for Hit a Target

Part characteristics	IMP	Positionitself precisely ↑	Ddurability of parts ↑	Able to operate for 8 hours ↑	A size of a motor proper for movements ↑	Non-rusting materials ↑	A clear maintenance manual O	Includes an on/off controller system ↑	Includes the small number joints ↓	A Qualified control system ↑	Includers wheels for movements O	Qualified circuit breakers ↑	Includers an indicator light O	
Function														
Cleanse a water tank thoroughly	17.86	9		3	1			1						
Long lifetime	9.84		9			3				1				
Price of the device	8.15	3		3	1							3		
characteristics														
Strong	7.84		9			3								
Cleanse a tank quickly	7.58	3		9	1			9						
Resistant-corrosion	6.75		1			9								
Material														
Friendly-eco	6.38					1	3							
Provides a maintenance manual	6.27				1		3					3		
Target values	6.19		9				9							
Safety														
Qualified device controllers	5.02									9		1		
Able to be moved easily	4.00										9			
Electrical leakage protecor nincludes	3.90											3		
Convenience														
Use durable materials	3.86		3			3				3				
Ncludes an indicator light turning on white operating	3.73												9	
Not corrode easily	2.61		1			3								Total
Raw score		207.9	180.1	202	31.71	124.2	37.95	141.8	0	66.6	36	59.98	33.57	1121.76
Importance weight (% Relative)		18.54	16.05	18	2.83	11.07	3.38	12.64	0	5.94	3.21	5.35	2.99	100
Rank		1	3	2	11	5	8	4	12	6	9	7	10	

Target values	Qualified device controllers	Structures made from ecofriendly materials	Strong and non-slip wheels	A proper size of motor	Durability of parts	A clear maintenance manual	A flexible system	Uses the least number of knots and screws	A qualified control system	Includes a base to be moved easily	Includes a brake	Includes an indicayor light

Fig. 7. The Relationship Matrix of the Part Deployment Matrix.

1. The Analysis of the Planning Matrix.

In this process, the researcher collaborated with the experts to identify the technical specifications that could meet user needs and determine the direction of device design and ways to improve the device in the future. The result of the Planning Matrix was shown in Fig. 7.

The weight of the technical specifications, called Raw Score, indicated how well the technical specifications fulfill user requirements. Therefore, the researcher compared the weights of each technical specification to measure the importance of weights. The calculation of the importance weights based on a comparison of "the length of the devices" was as follows [11].

The weights of the technical specifications (Raw Score) concerning "the length of the devices" = Σ (a score of the relationship between the user needs and the technical specifications X the importance ratings). The next step was to use the calculation results.

The relative importance weights of the technical specifications regarding "the length of the devices" = (Raw Score / Sum of the Raw Score) X 100%

The calculation result showed that the technical specifications with the top 3 highest relative importance weights were a position of movement (18.54%), continuous operation (18%), and eco-friendly materials (16.05%), respectively. Furthermore, these relative importance weights would be applied to the Part Deployment Matrix. The analysis of the second matrix was carried out in the same way as that of the Planning Matrix.

2. The Analysis of the Part Deployment Matrix

From the analysis of the Part Deployment Matrix in Figure 6 and the relative importance weights of part characteristics, it could be seen that the part characteristics with the top 3 highest relative importance weights were qualified device controllers (18.54), strong and non-slip wheels (18), and structures made from eco-friendly materials (16.05), respectively.

The analysis of the Part Deployment Matrix results in the part characteristics deployed for the design and the relative importance weights of the part characteristics. Moreover, it indicated which part characteristics could fulfill the user's needs the most or to what extent the part characteristics should be considered.

3. The Design of the Device. The results of the device design were as follows:

(1) The Device Consists of 3 Main Components:

The device design was the implementation of the part specification obtained through QFDE analysis as design data using a 3D design program in the virtual design of the device and defining materials for use in prototyping. Because this product was specialized, therefore, when designing environmentally friendly materials, it features lightweight, rust resistance and strength and required minimal energy consumption. The researcher chose to use Aluminum as the main building, soft and light metal with no lustrous appearance. Due to the thin layer of oxidation that occurred quickly when exposed to air, Aluminum metal was not toxic, not magnetic, and did not produce a spark. Pure Aluminum had a tensile strength of approximately 49 million Pascals (MPa) and 400 MPa if it was alloyed. In addition, Aluminum had a density of 1/3 that of steel and soft copper was easily ductile.

It could be easily machined and molded and resist corrosion and durability to be a prototype device.

Regarding the operation process in Fig. 8, the Process Chart was used to describe the process since it was an essential tool for recording data thoroughly and concisely. Moreover, it consisted of symbols, descriptions, and lines. Therefore, apart from expressing a production process in detail, this tool also helped an analyst fully comprehend every step in the production process and led to better work processes. In fact, the Process Chart could be divided into many charts; this research deployed the Flow Process Chart.

Fig. 8. Automated Guided Vehicle (AGV) From the Product Analysis and Design Matrix.

4.4. Controlling Phase

Control was the process aimed at maintaining the condition after improvements had been made to the manufacturing process. The following actions were carried out in the Control Phase:

1. Preparation of Work Instruction to indicate the correct work procedures and remove defects that may be caused as a result of the personnel's operation of the automated guided vehicle AGV;

2. Development of Check Sheet for inspection of characteristics of the specimens and automated guided vehicle (AGV); and

3. Formulation of maintenance plan for the automated guided vehicle AGV and accessories to prevent damage.

Documentations prepared had been used for internal controls of the Clinical Laboratory Section of Srinagarind Hospital to ensure maximum accuracy of transportation and achievement of the predetermined target.

5. Conclusions

This study was carried out to identify and reduce defects in the process of delivering specimens by using the Six Sigma approach consisting of five phases, including Defining, Measuring, Analyzing, Improving, and Controlling. The Failure Mode and Effect Analyze Process FMEA were also used to identify each cause's severity of effects on the defect studied. Quality Function Deployment or QFD was applied in combination with the FSUDEE technique. Concerning the design and development of the automated guided vehicle, data obtained from the analytic hierarchy process AHP were used for analysis in conjunction with the product planning matrix.

Improvements were made in accordance severity or high impact of the cause since these causes had a significant impact on defects and the potentiality, which might lead to delays in physician diagnosis processes; delays in receiving test results delay diagnosis and treatment. To solve the problem, a brainstorming session was conducted with relevant individuals. After improvements were made, the number of defects decreased continuously.

However, in terms of obstacles encountered in this research, data collection after improvements took a very long time due to the necessity for clarification of improved procedures, which involved the operation of the automated guided vehicle AGV and familiarizing personnel with the improved procedures.

The recommendations focus on maintenance training and learning how to operate the automated guided vehicle properly. This training should be

conducted frequently due to new personnel responsibilities and duties changes. In addition, education should be provided for personnel on quality tools. Therefore, hospitals or other agencies should encourage their personnel to realize the importance of transportation process quality, which would improve their overall performance and reduce the time expended in conveying specimens to their proper assessment stations.

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