Qualtiy Improvement in Plastic Based Toy Manufacturer Using Six Sigma Method

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***Abstract*—This research discuss the use of six sigma method such as Define, Measure, Analyse, Improve and Control (DMAIC) to improve quality. Object of the research is plastic based toy manufacturer which requires standard quality index of 99.845 Defect Per Million Opportunity (DPMO). In six sigma term it is equal with 2.78 sigma. This value can be achieved only if there is only defect less than 20.416 DPMO. In the measure phase, it is identified there are 2 critical to quality (CTQ) characteristics that bellow requirement. In the analyze phase, it is known that the main cause of failure is the improper material selection. After improvement and control phase, a signeficant quality improvement is achived.**

***Keywords*— quality improvement, six sigma, DMAIC, DPMO**

I. Introduction

Plastic based toys can be classified as complex products since the size is small but have a lot of components and accessories At a complex products such as plastic based toys, we ususally find there are many different types of nonconformities or defects can occur. Not all of these types of defects are equally important. A unit of product having one very serious defect would probably be classified as nonconforming to requirements.

This research will be focused on a plastic based toy in which market demand is increasing significantly. However the quality performance of this toy is very poor. This research will use six sigma method to improve such as Define, Measure, Analyse, Improve and Control (DMAIC).

Six sigma is a quality improvement program that aimed to improve management system and specifically aimed to improve production process by focusing on reducing process variances and reduce product defect. A related quality tools that being used is Failure and Mode Effect Analysis (FMEA). FMEA is a comprehensive tool, and used to identify and assess the risks associated with the potential source of a product or process failure.

II. Quality Theory Background

Quality is a slippery concept thus definition of quality is affected by individual perspective. Quality of products can be evaluated in many ways, therefore it is very important to categorize quality into its dimension. Garvin (1987) define there are 8 dimension of quality such as performance, features, reliability, conformance to standard, durability, seviceability, aesthetics and perceptions.

Complex products may have many different types of nonconformities or defects. A unit of complex product having one very serious defect would probably be classified as nonconforming to requirements, but a unit having several minor defects might not necessarily be nonconforming. In such situations, we need a method to classify nonconformities or defects according to severity and to weight the various types of defects in a reasonable manner. One possible demerit scheme is defined [1] . The number of demerits in the inspection units is defined as :

$$d_i = 100c_{iA} + 50c_{iB} + 10c_{iC} + c_{iD}$$

where c_{iA}, c_{iB}, c_{iC}, c_{iD} represent the number of Class A defects (very serious defect), Class B defects (serious defect), Class C defects (moderately serious defect), and Class D defects (minor defect) respectively in the ith inspection unit.The demerit weights of Class A-100, Class B-50, Class C-10 and Class D-1 are used fairly widely in practice. However, any reasonable set of weights appropriate for a specific problem may also be used.

Six sigma is a quality improvement program that aimed to improve management system in a company or other instance related with customer and specifically aimed to improve production process by focusing on reducing process variances and reduce product defect, so that the amount of defect is only 3.4 DPMO [2]. The number of standard defect based on sigma level can be viewed on tabel 1 as follow :

Tabel 1. The sigma level, DPMO and Yield

Sigma	DPMO	Yield
0.1	919243	8.1%
1	691462	30.9%
2	308538	69.1%
3	66807	93.3%
4	6210	99.38%
5	233	99.977%
6	3.4	99.999%

Quality improvement using six sigma aimed to improve quality by reducing defects into zero defects by controlling process variances. There are 5 phases in six sigma, they are *define, measure, analyze, improve* dan *control* or DMAIC. DMAIC can be explained shortly as follow:

1. Define Phase: In define Phase we define problem statement, project objective, scope, and background.
2. Measure Phase: Measure phase is used to show the root cause as detail as possible by showing data and cureent condition.
3. Analyze Phase: Analyze phase is designed to identify root cause and confirmied by data analysis.
4. Improve Phase: Improve phase is designed to implement and evaluate solution/ improvement that had been taken to solve the verified problem.
5. Control Phase: Control phase is designed to makesure that improvement that had been done can solve the problem along the time

III. RESEARCH OBJECT

The toys have a lot of components and accessories. Components and accessories of research object toys can be seen in table 2.

Table 2. Components of the toys

No	Komponen	Jml	No	Komponen	Jml
1	*Doll base*	1	9	*Groomed Head*	1
2	*Waist Clip*	1	10	*Bow Mask*	1
3	*Doll stand*	1	11	*Bows*	2
4	*Boots*	1 psg	12	*Basket*	1
5	*Costume*	1 set	13	*Torso*	1
6	*Wings*	1	14	*Skullette*	1
7	*Web Collar*	1	15	*Hairbrush*	1
8	*Earrings*	1 psg	16	*Carton Box*	1

Generally production process to make the toys can be seen in figure 1. The first process in toy making process is injection molding. Raw material in this process is plastic. There are some types of plastic, such as ABS (*Acrylonitrile Butadiene Styrene), PVC (Poly Vinyl Chloride), PP (Poly Propylene), Nylon, LDPE (Low Density Poly Ethylene), HIPS (High Impact Poly Styrene),* dan *Acetal.* Output of injection molding process is called molded parts, it can be doll accessories such as doll base, waist clip, torso, etc

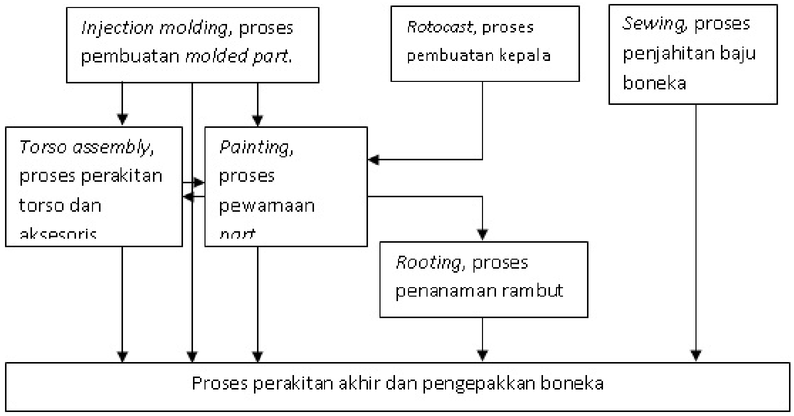


Figure 1. Plastic based Toys Production Proces

Head making process usually called roto casting process. Raw material in this process is PVC with lower hardness. Roto cast prosess doesn't use the same injection molding machine. All PVC resin are put in a big pot, then cooked using gas. After cooked, the PVC paste is streamed into some cast. By using sentrifuge force, the PVC paste will fill the cast evenly. Costume making is using sewing process. Costume design comes from designer in HongKong, meanwhile its pattern is made by local engineer.

Painting process is using 2 method, spray painting and tampo painting. Mostly all head are painted using tampo, and all accessories are painted using spray paint. Rooting process is rooting artificial hair into toy's head. The hair yarn usually made from fiber or nylon fiber. Rooting machine is very much like a sewing machine with some modification. After the head is fully rooted, we put glue inside its head, to make sure the hair yarn is not come out when it is pulled by children during playing the toy.

The process of final assembly and flapping done after all parts are available. This process is done manually, with tools. In this process, the head of the doll on the raft with his torso, fitted shirts, and other accessories, then packed into a package that has been determined. Once completed, the doll is inserted into the box, and ready to be sent to distributors.

IV. DMAIC Process

Define phase is the first step in the DMAIC method. In this phase needs to be defined background (problem statement), and objectives (goals) to be achieved. Quality of the toys is still very low. Preliminary research conducted to see the main cause of the low quality. The results showed that 68.4% of quality problem caused by the low quality of doll torso and its molded parts , as shown in the Pareto diagram in figure 2.

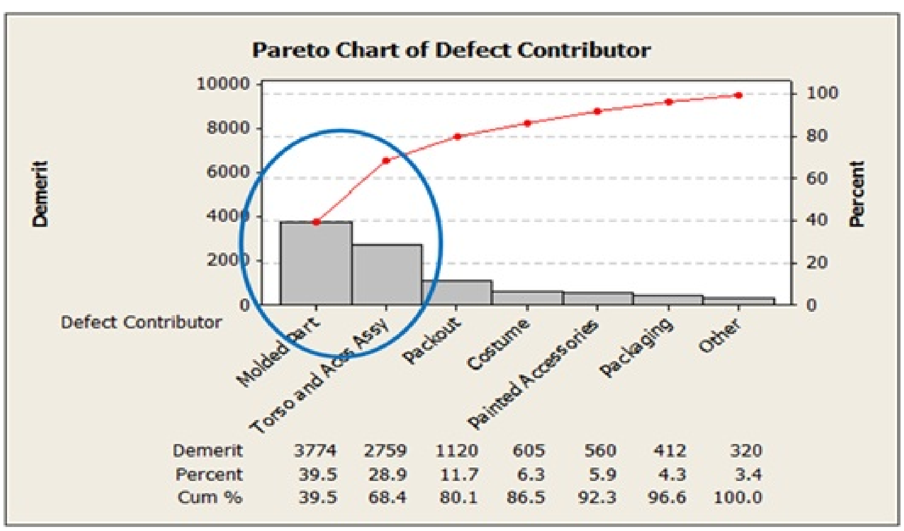


Figure 2 Causes of quality problems

Quality Index (QI) calculation using Demerit system, where each nonconformance products versus specifications (defect) will reduce the value of QI. Defects in aesthetics, functionality, reliability, and durability test of the product is weighted according to each category.

There are two categories namely major and minor defects. Major when the product does not work properly, while the minor when the product can meet the 80% - 100% product requirement. Weighting of defects attached in table 3.

Table 3. Weighting Defect type

No	Test	Category	Weight
1	Aesthetic	*Major*	10.25
		Minor	1.025
2	Function	*Major*	10.25
		Minor	1.025
3	Reliability	*Major*	10.25
		Minor	1.025
4	Durability	*Major*	6.8
		Minor	0.68

Here is the examples for the calculation of QI with Demerit system. For example the doll number N2851, was found 10 major defects during function test and 2 minor defects from aesthetic test, then QI for doll N2851 can be calculated as follows:

QI without defects = 100
Function defects = 10 x 10.25 = 102.5
Aesthetics defects= 2 x 1.025 = 2.05
QI doll N2851 = QI without defects – function defects – aesthetic defects = 100–102.5-2.05 = - 4.55

The more defects were found in the doll, then the Demerit getting bigger, and the lower QI. it is found that 81% of defects in the torso and molded parts occur in the function test. It can be stated that the low QI on the dolls is caused by the failure on the part or molded torso and testing functions. Therefore, this research will be focused on the torso and molded parts in function test. On the basis of the existing problems, the objectives are to improve torso and molded parts in function test so that defects in the torso and molded parts in function test does not exceed 20.416,67.

To achieve the desired objectives, and so-called CTQ, the target is to achieve defect-free MH torso. While the determinants (drivers) to produce defect-free torso are, aesthetics, functionality, reliability, and durability. These four determinants are then translated into seven character qualities that are more specific, so that it can be measured. In picture 6, it is seen that the defect in the function of the torso is very influential on the poor quality of the torso MH. The amount of defects in the function of the torso caused by CTQs function is not reached, the force to attach the hand is not in the range of 0-4 lbs, and the force to detach the hand is not in the range of 2-8lbs.

In accordance with the CTQ tree in define phase, we made a control chart $\bar{x}$ and R based on measurement result of attach wrist to lower arm force in figure 3 below. In figure it is clear that the force necessary to attach wrist to lower arm is highly variable and uncontrolled. This indicates that the variation is caused by the presence of a special cause, may be caused by human factors, equipment, material, environment, or working methods.

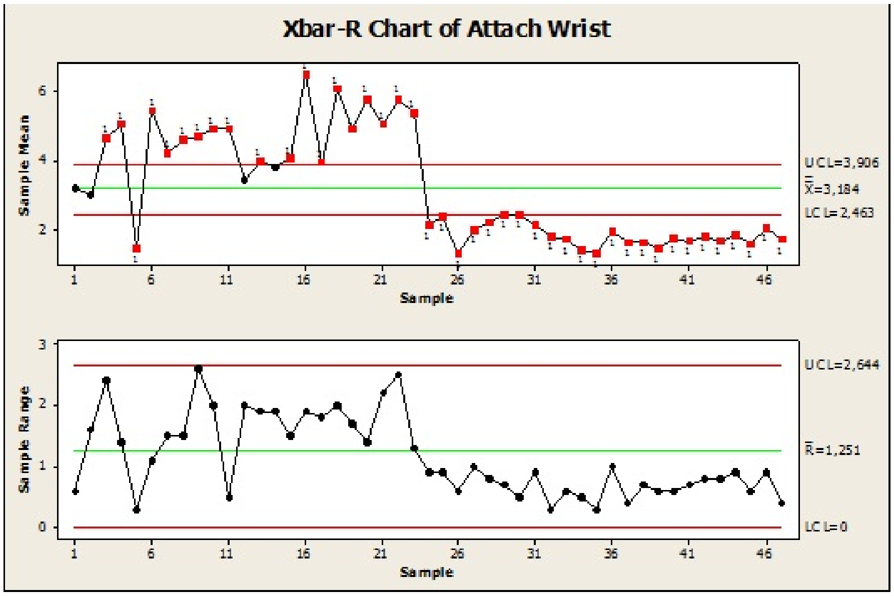


Figure 3. Control Chart $\bar{x}$ and R, force to attach wrist to lower arm

In addition to the control chart, we provide capability measurement products. Product capability can be seen in figure 4 below.

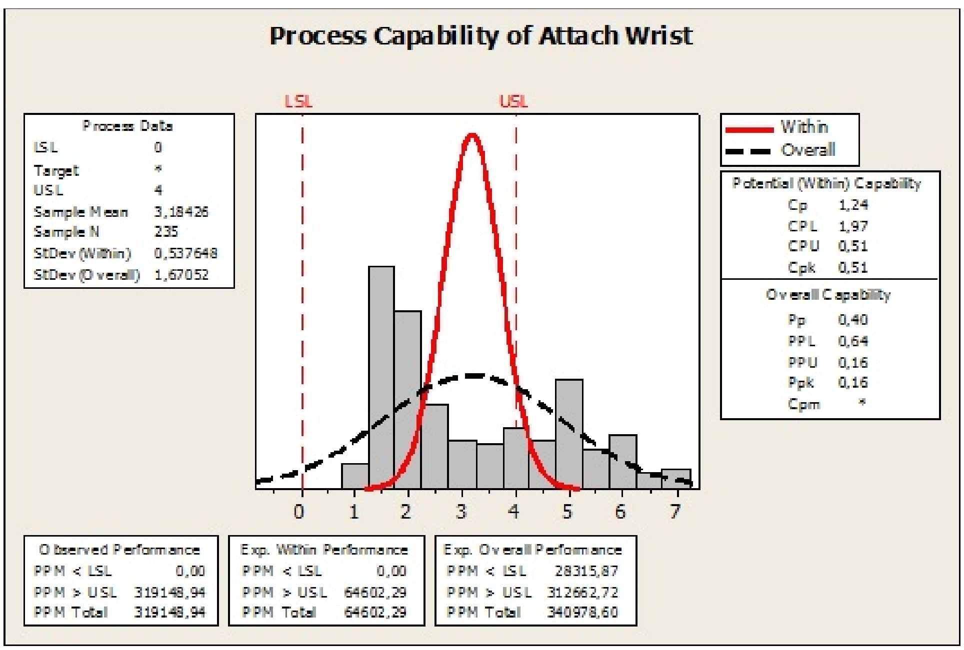


Figure 4.Cp and Cpk force to attach wrist to lower arm.

It can be seen that the Cp values is 1.24, indicating that the product is only able to meet the specifications in moderation. In addition Cp values are not the same as Cpk value indicates if the force to attach wrist to lower arm is not centered.

Control chart of detach force from wrist to lower arm can be seen in figure 5 below. It is clear that the force required to detach wrist from lower arm is very varied and uncontrolled (special cause).

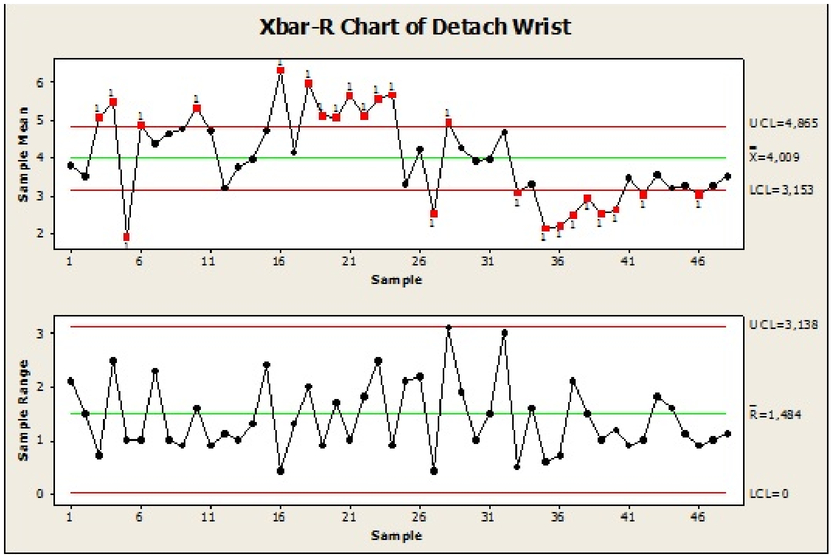


Figure 5. Control Chart $\bar{x}$ and R, force to detach wrist to lower arm.

Meanwhile the capabilities of the product, of detach force of wrist from lower arm can be seen in Figure 6..

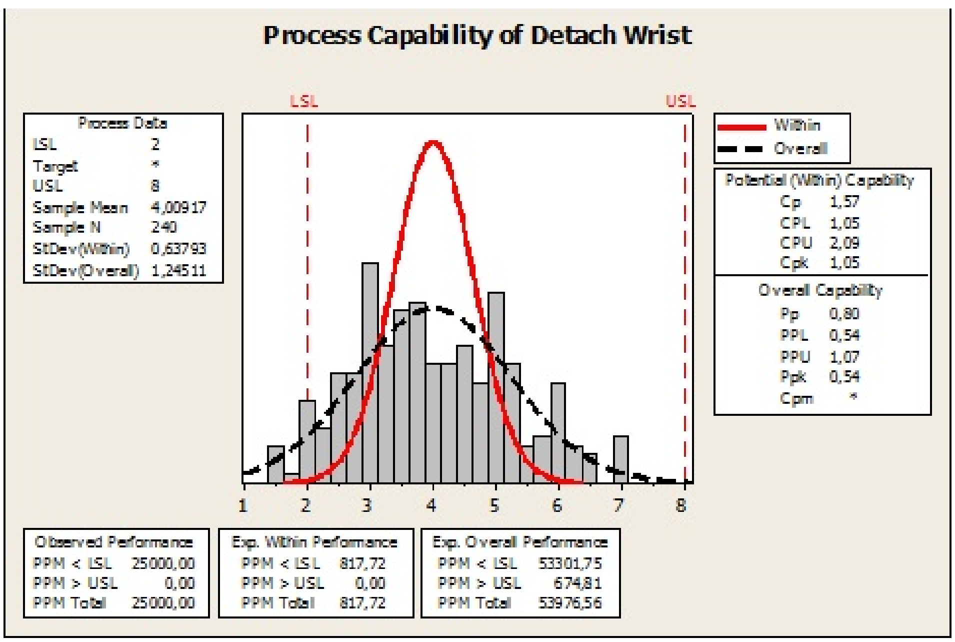


Figure 6. Cp dan Cpk force to detach wrist from lower arm.

It can also be seen that the value of Cp and Cpk are not equal, although the value of Cp on detach force is better than the attach force, but the since the Cp and Cpk value are not equal indicates that the force to detach wrist to lower arm is not centered.

To analyze the low capability of the product, we use fishbone diagram and FMEA to identify the root cause. The possibilities to consider are human factors, machines, methods, materials, and environments.

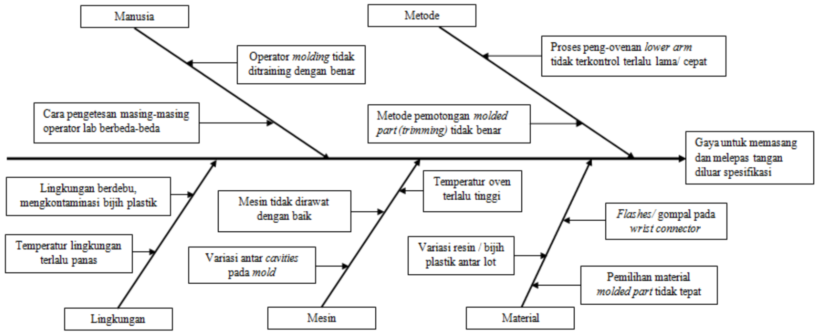


Figure 7 Fishbone Diagram

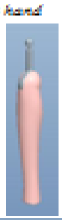
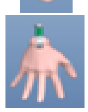
Fishbone diagram in figure 7 is developed base on direct observations on the production floor and brainstrorming with the engineering team.

FMEA is one of the six sigma tools that are routinely used in the company. FMEA is a comprehensive tool, and used to identify and assess the risks associated with the potential source of a product or process failure.

Table 4. FMEA

FAILURE MODE AND EFFECT ANALYSIS

Product Eng	: Lukito Rini	Toy	: Monster High	Date	: 17 Jan 2012
Quality Eng	: Rossy M	Part	: Torso	Revision	:
Tooling Eng	: Setiawan P	Age Grade	: 6+		
T/A Eng	: Aditya Adji	Eng ES	: Cesar Mora		
Mfg. Eng	: Rivai	Eng HK	: Chris Fong		

Component	Potensial failure Mode	Potensial effect of failure	SEV	Potensial Cause of Failure	OCC	Current control	DET	RPN	Recommended action
Lower arm & hand  	Gaya untuk melepas tangan lebih dari 8 lbs atau kurang dari 2 lbs	Gagal dalam pengetesan fungsi	8	Material *lower arm* terlalu keras (PVC 85)	9	Tidak ada	8	648	Ganti material dari PVC 85 ke PVC 65
		Gagal dalam pengetesan fungsi	8	Variasi pada tiap cavity *mold wrist connector* dan *lower arm*	5	Tidak ada	8	320	Cek kondisi aktual mold dan masing-masing cavitynya
		Variasi hasil pengetesan fungsi	8	Ada perbedaan metode pengetesan antar operator	5	Tidak ada	8	320	Pelatihan
		wrist connector patah saat dites	9	Pemakaian material yang terlalu sering di *regrind*	7	Dilepas pasang setelah tangan dirakit	5	315	Membatasi jumlah *regrind* yang diperbolehkan.
	Gaya untuk memasang tangan lebih dari 4 lbs	Gagal dalam pengetesan fungsi	8	Material *lower arm* terlalu keras (PVC 85)	9	Tidak ada	8	648	Ganti material dari PVC 85 ke PVC 65
		Gagal dalam pengetesan fungsi	8	Variasi pada tiap cavity *mold wrist connector* dan *lower arm*	5	Tidak ada	8	320	Cek aktual mold dan masing-masing cavitynya
		Variasi hasil pengetesan fungsi	8	Ada perbedaan metode pengetesan antar operator	5	Tidak ada	8	320	Pelatihan
		wrist connector patah saat dites	9	Pemakaian material yang terlalu sering di *regrind*	7	Dilepas pasang setelah dirakit	5	315	Membatasi jumlah *regrind* yang diperbolehkan
		Gagal dalam pengetesan fungsi	8	Proses peng-ovenan terlalu sebentar	5	Dilepas pasang setelah tangan dirakit	5	200	Pemasangan *automatic timer* pada oven

FMEA in table was conducted to identify and assess the risks associated with the potential source of product failures, in this case the force required to detach wrist from lower arm over 8lbs or less than 2 lbs and force to attach wrist to lower arm over 4lbs. For the first failure mode is the force required to detach wrist lower arm over 8lbs or less than 2lbs, the potential effect of failure is a failure that resulted in the testing function. Every single failure in the test function reduces QI product of 10.25 and therefore in terms of severity rated 8.

The main cause of this failure is due to the selection of material for lower arm is not appropriate. Currently the materials used are PVC 85, PVC material with a high degree of hardness (85). Consequently wrist connector will be difficult to be assembled in a hole inside lower arm, and also wrist connector will be difficult to be removed from lower arm holes. Improper use of the material will cause failure in all production lots, therefore the value of its occurences is 9.

This type of failure is quite difficult to detect, because it must be measured using a measuring instrument which is extensometer , in which if detection is done 100 percent, it will automatically increase production time. Therefore , checking and detection not done in production and it is only detected by using operator’s feeling. Therefore in this FMEA sheet the value of detection is 8 .

With a severity score 8 , occurences 9, and detectability 8 produces the largest value of the RPN among other causes , that is equal to 648 . The value of the RPN made this issue a priority to be solved , and from the results of brainstorming , team proposed to replace PVC material with a lower degree of hardness, and recommend to replace material for lower arm from PVC 85 into PVC 65 .

The second failure is caused by variation between cavities in the mold of wrist connector and lower arm mold. During lower arm and wrist assembly, wrist connector’s surface contact directly with the inner hole of lower arm. Currently there is 1 mold of wrist connector with 4 cavities and 2 pcs lower arm mold, left and right, with each mold having 4 cavities. Variations in the mold will produce parts with dimensions that are not exactly the same, but as long as the difference is not too big , it will not affect the magnitude of the force to attch and detach wrist to lower arm therefore its occurences rated 5. As for detectability, as well as the first cause, the variation in the mold can not be directly detected in the production process, because it requires the help of a measuring tool extensometer, in addition, the absence of the mold cavity number complicate the identification process. Thus, the value for the detectability equal to the first cause, that is 8, so that the overall value of RPN for the variation in the mold is 320 . To address the issue of variation in each of the cavities, the team recommends to check actual condition of all mold and compare with their mold drawings. If there is significant differences between drawing and actual conditon, team suggest to do modification on mold, but if not, team suggest to add cavity number on all wrist connector mold and lower arm mold.The next potential effect is the variation of testing methods between each laboratory operators. There are 8 laboratory operators, and special operators handling the MH dolls are only 2 people. Therefore, if the number of new MH dolls being developed is exceeding the capacity of the two operators, the other operators will be assigned to do the testing. Those unspecial operators may contributes to the variation of the test results. In this case team rate 5 for its occurences and 8 for detectability, because currently there are no measuring instruments or a certificate stating that the operator worth doing MH doll test.

The next potential effect of failure is a broken wrist connector during function test. This condition is very severe although not causing a safety or security issue , but if wrist connector is broken, then the product can not be used again, the wrist can not be attached to the lower arm. Due to the higher level of seriousness, the team gives the value of 9 for its severity . Wrist connector breakage can be caused by the use of non-virgin material (nylon that has been regrinded over and over) . The company 's policy is to reduce production costs by reusing the rejected molded parts , by means of regrind, and used again in the injection molding process . The use of regrind materials is quite high, resulting in the incidence of wrist fractures in production floor, so the team gave a score of 7 for the occurence , while its detectability is 5 because it can be detected by attaching and detaching wrist to lower arm. With a severity value 9, occurence 7, and 5 for detectability, results high enough RPN value, 315. The use of recycled materials will not be a problem as long as the material characteristics have not changed. Material characteristics will change once it had been regrind more than 3 times, therefore the team suggested that the use of recycled materials is limited only until 3 times regrinding, and make identification of the recycled material, so that the material to be used only materials that have been recycled maximum 3 times, and the rest that have been regrind more than 3 times must be scrapped directly.

In the improve phase, all improvements based on the analysis that had been done at the Analyze phase are implemented, so that problems can be reduced or eventually eliminated. Process improvements made by team, is based on the recommendations that have been generated FMEA. They are:

Changing the type of PVC material for lower arm from PVC 85 to 65. We conducted experiments with small-scale 48 sets of torso to check the impact of the improvement. In this experiment no problems found during injection molding process. There’s no more oven process for lower arm before lower arm and wrist assembly, since the material for lower arm is softer and both parts still can be assembled easily.

Product capability with the change of the material from PVC 85 to 65 can be seen in picture 4.10. In this picture, it can be seen that the Cp value is 2.23, indicates that the condition of the product is now able to meet the specifications of the product well, although Cp and Cpk value still not equal , which indicates that the process is not centralized, but the picture shows that there are no products that out of specification, all still between values of 0 and 4lbs . Thus all of the products are still in the specification, and automatically QI will increase because there is no weight that will reduce the value of QI with Demerit system

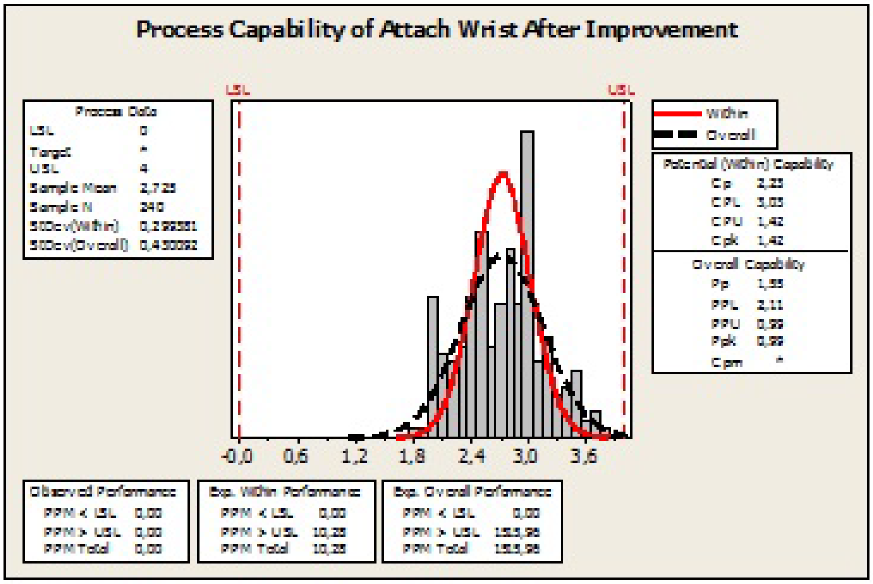


Figure 8. Cp dan Cpk of Force to attach wrist to lower arm using PVC 65

Product capability of force for detaching wrist to lower arm after material changing can be seen in figure 9.

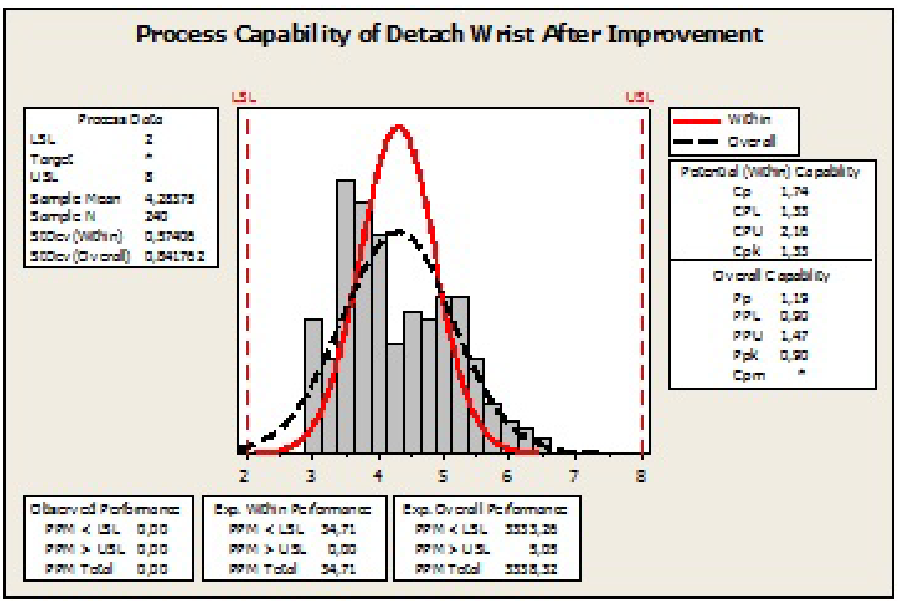


Figure 9. Cp dan Cpk of force to detach wrist to lower arm using PVC 65

It can be seen that the Cp value is 1.74, indicates that the condition of the product is now able to meet the specifications of the product well, although Cp Cpk value still not equal, which indicates that the process is not centralized, but the picture shows that there are no products that out of specification. Thus all of the products are still in the specification, and automatically QI will increase because there is no weight will reduce the value of QI with Demerit system. Both pictures and data show that material changing from PVC 85 to PVC 65 bring positive results.

The second improvement is checking actual condition of each mold. Checking is done by comparing the actual condition of mold and mold drawing. If all mold are in good condition, then need to add cavity number on all mold for better tracing and identification if a new problem occurs.

The third improvement is training for functional, life, reliability, and durability test for MH dolls. The training are prioritized for the non MH dolls laboratory operators. At the end of the training, there will be a test to see how far lab operator understand of how proper they perform testing. Only operator that passed the test that allowed to check MH dolls.

The fourth improvement is making control tag to control material regrind process. These tags will be attached in resin bag, so that the quality personnel can easily identified whether resin inside bags still can be used for injection molding or not.

V. CONTROL PHASE AND CONCLUSION

To control the dimensions and shape of the molded parts, it needs quality control measurements of critical dimensions and visual checking. In this project, critical dimension is the dimension of surface that will be in contact after the parts are assembled, they are the dimension of the wrist connector that shaped like a ball and the hole inside lower arm. If the measurement is made using a caliper, then most likely there will be variations in measurement between operators. Thus it is proposed to provide tools for checking, in this case the tool is a go-no go jig. The mechanism of this jig is, if the dimensions and shape of the corresponding part within specification, then the part can go thru the tools, but if the shape and dimensions of the parts are not within specification, the part can not go thru the tools.

Once Six Sigma project is implemented, we performed checking on first QI of FEP, to see the effectiveness of the project. From the data obtained, the average first QI a significant increase, from an average of the first QI 336.27, to 5.46.

Based on the stages ranging from Six Sigma define, measure, analyze, improve, and control that has been done, it can be concluded through the FMEA method, based on the largest value of RPN, it is known that the main cause of failure is the improper material selection for lower arm, too hard. In the improve phase, carried out improvement based on FMEA analysis, material replacement for lower arm from PVC 85 to PVC 65, mold checking for wrist connector and lower arm, adding cavity number on the lower arm's mold , and provision of periodic training for lab operators.

In the control phase we made standard form to facilitate data retrieval for lab operator to take data and check the condition of the torso, and propose to provide go-nogo jig to facilitate dimension and shape checking of molded parts. At this phase it is found a significant increase of the average first from -336.27 to 5.46

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BIOGRAPHY

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