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Research paper

Six Sigma Analyze Phase for New Product Development Prototype Process Improvement

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Abstract

Many manufacturing companies focus on the innovative product. Prototyping process plays a very important role for innovative product because prototype helps the company to test the functionality and stability of a product. The popularity of the product on the market also can be done by using prototype to determine the customer interest on the product. This study is conducted at research and development department of a stationeries products company. The purpose of this study is to reduce the total duration of prototyping process by using Six Sigma phase. This article focusing on analyse phase of this study where the cause and effect diagram, failure mode and effect analysis and pareto chart were used to determine the major causes of the problem. Once the major causes were identified, a solution plan was proposed in Improve phase. Results and findings for this analyze phase explaining about top level process overview to visualize the whole research and development structure interaction with prototyping process and how cause and effect diagram being further elaborate focusing on poor prototyping process visibility and process duration too long.

***Keywords*:** *Six sigma; prototype process improvement; new product development; analyse phase; case study*

1. Introduction

Six Sigma is a management methodology which allows companies to use data to eliminate defects in any process. For a process to have achieved Six Sigma, a process must not produce a defect - that is anything outside of customer specifications - more often than 3.4 times per million opportunities. Six Sigma works through the use of two sub methodologies; DMAIC which stands for Define, Measure, Analyse, Improve and Control and is used for existing processes, and DMADV which is used for new processes and stands for Define, Measure, Analyse, Design and Verify.

Implementing Six Sigma within a business offers a number of benefits and key advantages such as improved customer loyalty, time management, reduced cycle time, employee motivation, strategic planning & supply chain management (Amy Harris, 2013). Six Sigma is a business enhancement methodology that aims to capitalize on shareholder value by improving quality, speed, customer satisfaction and costs. Six Sigma project is conducted by using the DMAIC methodology. The DMAIC methodology consists of five phases: Define phase, Measure phase, Analyse phase, Improve phase, and Control phase. These stages are planned to get the team through a step-by-step process improvement and it starts from inception to completion (Wheeler, 2010).

Many companies have attempted to introduce Six Sigma practices into New Product Development (NPD) stage because Six Sigma practices are a customer-focused methodology that improves the product's quality and optimizes organization's financial performance (Chua, 2001). NPD is the most important touchstones for a manufacturing company to maintain and achieve competitive advantage. The potential value of NPD is boundless and the design only limited because of an individual's creativity. Six Sigma also described as a method applied to improve existing process and create new process. The customer demands for new product increased in term of innovation, speed, quality, product performance, and function. The NPD process should be improvised as the customer requirement change. It is important for a company to satisfy the customer demand in order to remain competitive in the market (Linderman, 2003). Therefore, this study focused on the implementation of Six Sigma practice into NPD.

The objective of this article is to investigate analyse phase of new product development prototype process improvement using six sigma methodology and tools in stationaries assembly manufacturing line. FEMA Stationery Sdn Bhd is providing stationeries supply services in Malaysia, Singapore, Taiwan, Arab Saudi, Hong Kong and China. The company offer a wide range of products group including paper stationery, office and school stationery supplies, writing ink, writing utensils, staples, crayons, letter openers, pencil cases, chalk boards, memo boxes, file rings, push pins and adhesives, stationery set, art materials and corporate souvenir and gift items and dedicate to provide the best sourcing and highest quality stationery products to the customers. The main manufacturing is located in Bangladesh and they have a branch office in Malaysia to handle daily sales activities to provide over 5000 kinds of different stationery products to clients including to provide OEM stationery products service for the worldwide customers. FEMA main business challenges are around the cost of manufacturing the products, new product development prototype process, global organization management structure, sales and marketing strategy to penetrate global market and product branding. Cost of manufacturing stationeries product mainly related to

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direct manpower or labour cost because of stationeries production mainly involve in manual assembly. So any country in the world which able to provide lower labor assembly cost will be the first option to consider establishes the production line there. The second challenge is about new product development prototype process which has direct major impact to the sale and marketing strategy.

This article is arranged as follows. The first introduction section briefly explains about Six Sigma management methodology introduction into New Product Development (NPD) stages and the objective of this article to investigate the analyse phase of new product development prototype process improvement. The second section explains about the literature review which focusing on new product development (NPD), cause and effect diagram, Failure Mode and Effect Analysis (FMEA) and action plan table. This was followed by the methods employed in this research with brief explanation about potential improvement is prototyping process to achieve target total product development duration. The third section about results and findings started to visualize the whole process structure interaction between new product development framework and prototyping process. Cause and effect diagram for poor prototyping process transparency and process duration taken too long to complete has been explained including FMEA table for overall prototype process flow, part readiness, assembly build and test phase and closed with potential failures pareto chart and action plan table. The fourth and the final section is about the conclusion from the analyze phase which are all the potential causes of the problems had been brainstormed and an action plan for all the potential causes has been created.

2 Literature Review

New product development (NPD) is the development of original products, product improvements, product modifications, and new brands through the company own research and development (R&D) efforts" (Kotler and Armstrong, 2010). NPD is a high risk activity but also is a most vital strategy for manufacturing industries (Clark et al., 2006). The participation of customers plays an important role for NPD. However, even among some company with millions of customers, only few company that will have the willingness to fully engaged with participation of customers in the product development (O'Hern and Rindfleisc, 2009). The perceptive of customer needed for the purpose of prioritize customer value is most crucial for a company.

A market oriented NPD is "The development of new product, which is based on the generation of market information, the dissemination of the information across department and responsiveness of various department to it" (Kohli and Jaworski, 1990). A new product is introduced to the market and the ability to get attentions from the market always is the main focus of the company marketing strategy (Mccole and Ramsey, 2005). The speed for the process of NPD is critical because nowadays product life cycles are shrinking and end of life for product is shorter compare with the past. Reducing development time is a key factor to achieve competitive advantage (Cooper, 2001). Companies that develop products quickly gain many advantages over competitors: premium prices, valuable market information, leadership reputation with consumers, lower development costs, and accelerated learning (Cooper, 2001).

The relationship between R & D and Marketing in product development has been the interest for researcher all the time. In a NPD, large technologically intensive companies deserve special attention because unlike smaller businesses, big companies in better position to carry out technologically innovative systematic activities in product development process (PDP). In many cases, large companies have sufficient resources for this type of work, such as adequate installations, machinery and labour. Integration between R&D and PDP is defined as interactive and collaborative studies between different roles and company specialists with the purpose of creating knowledge and/or technological solutions that are transferrable to one or more products during the development of these products (Nobelius et.al, 2004).

2.1. Analyse Phase

To solve a problem, one need to perform root-cause analysis, anticipate any problems that could prevent effective implementation, perform regression analysis to establish, and perform hypothesis testing to evaluate the new processes (Praveen Gupta, 2005). There are many tools that can be used for root causes analysis and solution development. The main objectives is to reveal the root cause of problems. Table 2.3 shows the tollgate review of Analyze phase.

Table 2.1 Analyze Tollgate Review

A – Analyze Phase: Analyze and determine the root cause(s) of the defects.	
DMAIC Phase Steps	Tool Used
Determine Root Cause(s)	Cause and effect diagram FMEA Pareto Chart
Solution for root causes	Action plan table

2.1.1. Cause and Effect Diagram

The goals for cause and effect diagram are to support the team in brainstorming possible causes, visualize the possible causes, and depict the relation between possible causes. To construct a cause and effect diagram, the problems must be clearly defined and the team members must be identified (Alexander John, 2008). There are seven steps in constructing a cause and effect diagram as follows (Praveen Gupta, 2005):

i. Identify and state the problem to be solved.
ii. Ensure that the right people are present during the construction of the causes and effect chart.
iii. Construct main branches and label them into people, material, method, machine these four categories.
iv. Conduct a brainstorming session to identify potential causes.
v. Ask why this problem occurs and write down the answer below the problem.
vi. Prioritize the most suitable cause for corrective action.
vii. Decide which cause is most likely the root cause.

2.1.2 Failure Mode and Effect Analysis (FMEA)

The goals for failure mode and effect analysis are to identify causes and check for potential weak points, assess risks for the customer of a process and specify priorities for the further analysis (Alexander John (2008). FMEA is a risk minimization technique that helps the organization identifies a risk with a proposed solution in a Six Sigma project (Praveen Gupta, 2005). FMEA methodology consists of grading failure modes for severity, potential causes for occurrence, and controls for detections.

Severity: This involves the seriousness of the effect of the potential failure mode on the functionality of the product or on customer applications. It gives an idea of the resulting loss generated directly or by adverse effects on the subsequent operational steps. The severity is graded on a scale of 1 to 10, where 10 relates to a life-threatening situation, and 1 implies minimal effect.

Occurrence: This represents the frequency with which a causes of potential failure may occur. The frequency of occurrence is estimated based on the process knowledge and the historical performance. In the absence of historical data or knowledge, the frequency of occurrence may be estimated based on similar processes, or as determined by the cross-functional team. The occurrence is graded on a scale of 1 to 10, where 10 imply certainty of an event, and 1 implies a hypothetical situation.

Detection: This represents the relative probability with which the effect of a cause can be detected through appropriate controls. Detection is also graded on a scale of 1 to 10, where 10 imply

difficulty in detection, and 1 implies a certain containment of adversely affected material.

2.1.3 Action Plan Table

Action plan table is a solution plan for future actions. All the causes are studied and identified. Suitable solutions can be proposed by the team members to solve the problems. The action plan table helps customers to understand what are the solutions available and what are the steps required to solve the problems.

3. Methodology

Several projects were found had some problems to achieve the target total product development duration due to some issues suspected related to the product development processes. One of the processes that had been identified by the company which need to make an improvement is prototyping process. Several problems that were raised by many departments involved in the new product development project are delayed completion of prototyping parts and assembly, the confusion about the part readiness status, and disorganization of the management of prototype activities. The main challenge which gives a very high impact in the prototyping process is the total duration of the prototype build. The delay of a new product launched caused the loss of the competitive advantage for the product in the market.

3.1 Goal Statement

i. To determine the type of measurement for prototyping process.
ii. To determine the main causes for delay completion of prototyping process.
iii. To reduce the total duration of prototype build process by 15 percent.

3.2 Project Scope

For this case study, the focus scope is the process time study that involved the duration to complete prototyping process from CAD drawing release until part product assembly and ready for testing. The idea generation of new product development process is excluded in the scope because the time frame to generate a new idea could not be guarantee. Standard prototyping benchmark plans, capacity development, engineering build process and governance management are also excluded from the project scope.

3.3 Project Team

The project team has been developed to solve the problems of this case study. The members of project team consisted of business process team, product engineers, project managers, design manager, and engineer leaders. Each member has their own role and responsibilities respectively. Table 3.1 explains the role, responsibility, and commitment of every project team member. The role of business process team as the leader of the project team because the relationship between business process team and prototyping process are very strong. The business process team requires a new product ready to launch into the market anytime to maintain the sales of the company. The business process team is responsible for research of the project management, work with the breakdown structure and task assignment of the entire team, and provides directions and supports to the team members. Thus, a full commitment is requires from the business process team in this case. The product engineers act as a co-leader in this case. The product engineers need to analyse the data collected and develop a solution for this case. The roles of product engineers are important in this case. There is an expectation for their commitment. The project manager, design manager, and engineer leader are the members of this project team. Project manager is responsible to develop a plan for prototyping process and collect the data. The responsibility of design manager is the consultation for the part and product assembly design. Engineer leader is assigns to release the drawing of part and assembly and plan the processes for the part and assembly.

3.4 Project Plan and Schedule

Project plan was constructed and acted as the project Gantt Chart to ensure the progress of the case study. Every phase of DMAIC method was given a timeframe. There are activities required to complete for each phase. The project team was required to complete all the activities within the timeframe. **Table 3.2** shows the project plan for DMAIC phase with the duration and the activities for each phase. However, this article will explain only for ANALYSE PHASE.

Table 3.1: Project Team table

No	Position	Role	Responsibility	Commitment (percent)
1	Business Process Team	Leader	• Research project management • Work breakdown structure and task assignment to team members • Provide direction and support to the whole team	100
2	Product Engineer	Co-Leader	• Analyse the data collected and develop a solution	50
3	Project Manager	Team member	• Prototype builds planning • Collect data	30
4	Design Manager	Team member	• Part and product assembly design consultation	30
5	Engineer Leader	Team member	• Part and assembly drawing and processes planning	30

Table 3.2: Project plan Gantt Chart

Phase	Activity	Duration							
		Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17
DEFINE	Develop project charter								
	Formulate project plan								
	Draw SIPOC								
	Collect customer requirements								
MEASURE	Identify and define measurements								
	Data collection plan								
	Collect data								
ANALYZE	Collect all possible causes								

	Analyse data								
	Verify root causes								
	Construct action plan table								
IMPROVE	Collect possible solutions								
	Select solutions								
	Elaborate action plan for implementation								
	Test and implement solutions								
CON-TROL	Determine the efficiency of improvement								
	Finalize documentation								
	Implement effective, long-term monitoring								

4 Results and Findings

Figure 4.1 shows the top level process overview to visualize the whole process structure interaction between new product development framework and prototyping process. New product research and development framework normally consists of three phases which are New Product Introduction (NPI), New Product Development (NPD) and Production (Product Launch). Prototyping process is the sub-process within new product development process group which is build up from a few cycles of Design-Build-Test process. The focus area of the case is the build process. Build process consists of three prototyping processes which are Preparation phase, Part Readiness phase, and Build and Test phase.

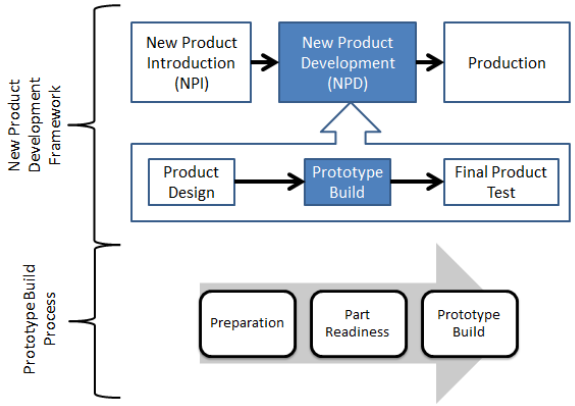


Fig 4.1: R&D framework top down structure to prototype build process

4.1 Cause and Effect Diagram

Two main problems highlighted in previous phase, which are prototype poor process visibility and prototyping process duration too long. The causes and effects of each main problem are shown using causes and effect diagram.

Figure 4.2 shows the causes and effects of the poor process transparency problem. The poor transparency of the process was defined through the VOC. For the prototyping parts, there are no tracker documents for the part readiness status. There is also no auto and live reporting document from the machine system. The tracking system and process are not centralized. For the manpower part, the process flow training and guideline are not available. Those new engineers who just joined the company are still under training. The coordination between project team and engineer team is poor and the communication for both teams should be strengthened. For material part, the procurement processes for standard parts are not standardized. The process should be standardized. The prototype request and status update system are not documented properly and create confusion for the quantity of the parts available. For method part, there is no standard guideline on how to manage and govern the process flow. Every department has their own different process and guideline to follow. All the departments do not have a standard process flow and guideline training.

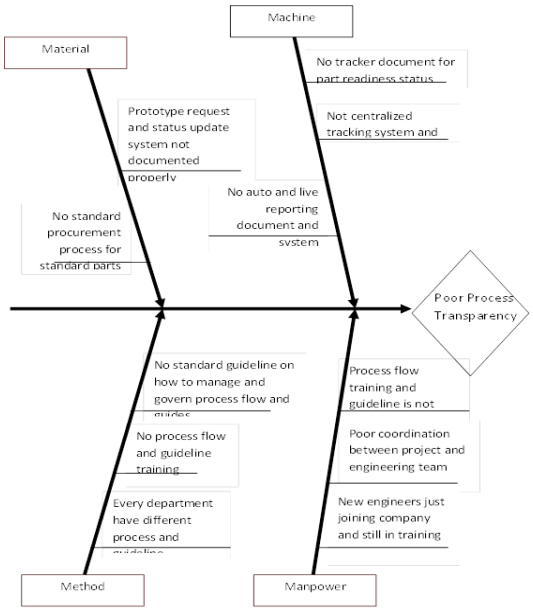


Fig 4.2: Cause and Effect diagram for poor process transparency

From the Define phase, another problem that defined through VOC is prototyping process duration take longer time to complete. Figure 4.3 explains the causes and effects of the problem. For the machine part, the BOM and drawing release system is not up to date. Any changes that make on BOM and drawing release system after that cause an additional work to be complete.

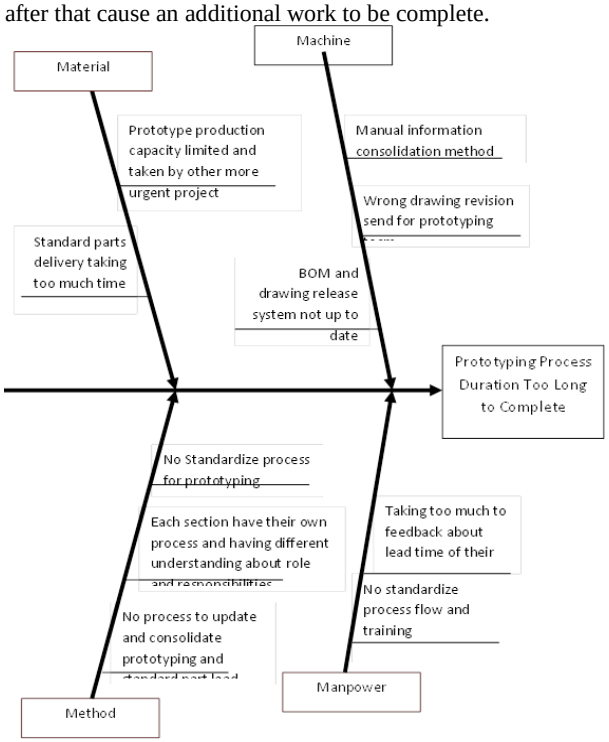


Fig. 4.3: Cause and Effect diagram for prototyping process duration too long to complete

The information consolidation method still using the manual way and it takes time. There is also time that the prototype team received the wrong drawing. For manpower part, there are no standardized process flow and training. It also takes too much time from the person in charge to feedback about the lead time of their respective parts. For material part, the prototype production capacity is limited, and there is time that some urgent project required to use the machine and then stopped the prototype production process. The standard parts purchased for prototype also taking too much time to delivery. For the method part, every section has their own process and having different understandings about their role and responsibilities. It makes the priority of the prototype production are not in the same page. The prototype production would not run until it reaches the urgent level. The processes of prototyping are not standardized and there is no process to update and consolidate prototyping and standard part lead time.

4.2 FMEA

After the potential root causes were analysed, each process step potential failure were evaluated and assigned a score on a scale of 1 to 10 for the severity, occurrence and detection variables. Table 4.4 explains the rating scale from 1 to 10 for severity, occurrence and detection. Each rating scale is given based on the severity of the failure, the occurrence of the failure and the detection level for the failure.

Table 4.4: FMEA rating scale for Severity, Occurrence, and Detection

Rating scale	Severity description (S)	Occurrence (O)	Detection (D)
10	Dangerously high	Very high: Failure is almost inevitable	Absolutely uncertainty
9	Extremely high	High: Failures occur almost as often as not	Very remote
8	Very high	High: Repeated failures	Remote
7	High	High: Failures occur often	Very low
6	Moderate	Moderately High: Frequent failures	Low
5	Low	Moderate: Occasional failures	Moderate
4	Very low	Moderately Low: Infrequent failures	Moderately high
3	Minor	Low: Relatively few failures	High
2	Very minor	Low: Failures are few and far between	Very high
1	None	Remote: Failure is unlikely	Almost certain

Table 4.5 shows the FMEA for the overall prototype process flow. There are two potential failures which are poor transparency and governance for prototype process flow and employee attitude problems. The effect of the poor transparency and governance failure is extremely high because it makes the prototype build plan failed. The causes why the prototype process flow has poor transparency and governance is because the current prototyping process is not transparent and there are no guidelines to follow. This failure occurred repeatedly and frequently. The failure only able to detect after the prototype build plan failed. It is very low chance to detect it from the starting points. For employee attitude problems failure, it affects the team moral become lower and creates frustration among the team. This effects considers moderate because some employee stays motivated themselves most of the time. The cause for this failure is relatively low because the working environment provided by the company does not make the employee feel more stress. Employees would have attitude problems, mainly because of their personal issues. The detection for this failure is moderately high because other employees can feedback to the respective assembly leader when they notice one of the employees having some problems.

Table 4.5: FMEA Table for overall prototype process flow

Potential failure mode	Potential effects of failure	S	Probable causes	O	Process control/ detection	D	RPN
Prototype process flow and guidelines - poor transparency & governance	Prototype build plan failed due to parts not ready on time	9	Current prototyping process is not transparent and there are not guideline to follow	8	Only detect after build plan failed	7	504
Employee attitude problems	Low team moral and frustration	6	The working environment is too stress and employee personal issues	3	Feedback to respective assembly leaders	4	72

Table 4.6 shows the FMEA for the Part Readiness phase. For Part Readiness phase, one of the potential failures is part tracking and prototyping build status information are not in centralize database. The effects of part tracking and prototyping build status information are not in a centralize database is very high because the prototype build plan delayed for this failure. The probable cause for this failure is no guideline to track the work in the progress and this failure occur occasionally moderately. The detection for this failure is low because it only detects after the build plan delayed. Another failure for Part Readiness phase is team work in a silo mentality. Every product assembly team has their own different plan to freeze the CAD file and release the drawing, but these not really create a significant effect. There is no systematic method to centralize the information and the occurrence of this failure is often occurring in high range. The detection level for this failure is moderate because it lower down the performance before the team leader able to notice. Once the performance become badly, the team members should report to the team leader and some actions should be taken.

Table 4.6: FMEA Table for Part Readiness Phase

Potential failure mode	Potential effects of failure	S	Probable causes	O	Process control/ detection	D	RPN
Part tracking and prototyping build status information is not in centralize database	Prototype build plan delayed	8	No guidelines to track the work in the progress	5	Only detect after build plan delayed	6	240
Team work in silo mentality	Every product assembly team will have different plan to freeze CAD and release drawing	5	Silo mentality and no systematic method to centralize the information	7	Report to the team leader	5	175

Table 4.7 shows the FMEA for the Build and Test phase. The potential failures for this phase are there is no update and slow responses for the part readiness and build status and not enough standard parts for prototyping. The effect of no updates and slow respond is low because the product engineer could ask offline and chase the respective member for the status update. This is a frequent failure because the unclear role and responsibilities of members and they do not aware what are their priorities. However, the detection for this failure is remote. It only detects after the product engineer feedback and the management escalation. When there is not enough standard part for prototyping, the build process stops and need to reschedule for next build. It is a high severity for this failure. The cause for this failure is because of the supplier delayed delivery of the standard parts but the occurrence is moderately low. If the failure does happen, the engineer should feed-

back to the respective procurement manager to study the situation. The detection level is moderate for this failure.

Table 4.7: FMEA Table for Build and Test phase

Potential failure mode	Potential effects of failure	S	Probable causes	O	Process control/ detection	D	RPN
Part readiness and build status - no updates and slow respond	Product engineer need to offline ask and chase respective members for part and assembly build status update	5	Unclear role and responsibilities of members causes they not aware what are their priority	6	Only detect after product engineer feedback and management escalation	8	240
Not enough standard part	Build stopped and need to reschedule	7	Supplier delayed delivery of standard parts	4	Feedback to respective procurement manager	5	140

4.3.3 Pareto Chart

Based on Figure 4.8, there are four potential failures that require to give an immediate reaction according to the 80:20 rules of Pareto chart. The four potential failures are prototype process flow and guidelines, part tracking and prototyping build status information is not in a centralized database, part readiness and build status, and team work in a silo mentality. An action plan should be conducted for these four potential failures. Although the potential failures like not enough standard part and an employee attitude problem is not in the 80% of the Pareto chart, it does not mean that these failures should be ignored. It only shows that this failure is not the top priority. The action for these two failures can be taken if the actions are not costly.

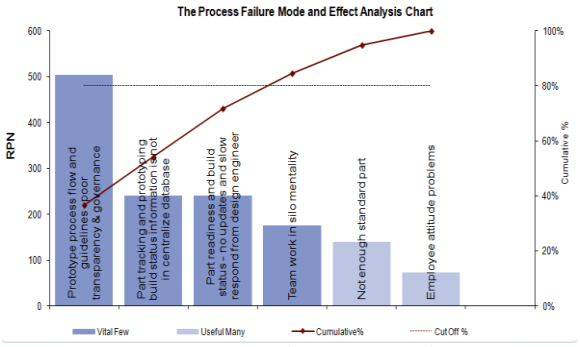


Fig. 4.8: Pareto chart for the potential failures

4.3.4 Action Plan Table

The main causes of the problem are identified. An action plan was constructed to determine the next level actions for the causes respectively. Table 4.9 shows the potential failures and their action plan.

Table 4.9: Action Plan Table

Process step	Potential X	Impact on Y	Priority / action plan
Prototype process flow	Prototype process flow and guideline - poor transparency & governance	Prototype build plan failed due to parts not ready on time	-Cross department brainstorming workshop -Cleansed current documents and process mapping. -Develop agreed process flow and guidelines
	Employee attitude problems	Low team moral and frustration	-Arrange cross department training and guideline briefing
Part readiness	Part tracking and prototyping build status information is not in centralize database	Prototype build plan delayed	-Develop a cleansed guideline to track the work in the progress
	Team work in silo mentality	Every product assembly team will have different plan to freeze CAD and release drawing	-Develop scrum daily morning meeting module
Build and test	Part readiness and build status - no updates and slow respond from design engineer	Product engineer need to offline ask and chase respective design engineer for part and assembly build status update	-Specify the role and responsibilities of the members -Make sure members know when is the time they should put priority on prototype work
	Not enough standard part	Build stopped and need to reschedule	-Develop centralized parts and build status tracker document

5 Conclusion

From the Analyze phase, all the potential causes of the problems had been brainstormed. An FMEA table is constructed to determine their risk priority number. The main causes of the problems are determined by using the Pareto Chart. The main causes are the process flows are not standardized, unclear role and responsibilities of team member, and no guidelines for documentations. An action plan for all the potential causes has been created.

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