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VERTICAL ANALYSIS OF THE 6M IN PFMEA TO REDUCE DATA ANALYSIS AND IMPROVE SYSTEM PERFORMANCE

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ABSTRACT

Process Failure Mode Effects Analysis (PFMEA) is a well-defined process of identifying and analysing the process failure risks and assessing the effects of the same. This process is generally carried out in any organization by a cross functional team of different departments within the organisation. One of the main steps in any PFMEA is the 6M analysis and its conventional analysis. Although the process is extremely important in the organisation, it is extremely tedious and time consuming. To overcome this issue, this paper aims at reducing the time taken by the process by changing the analysis procedure in the 6M analysis.

KEYWORDS: PFMEA, 6M analysis, process failure risks

1. INTRODUCTION

Every automobile manufacturer today strives to continuously improve the quality of its products it offers into the market. This is achieved by controlling the design, process and the financial parameters of the product. The extent to which this can be achieved decides the feasibility and the competitiveness of the product in the market. Companies invest immensely into the process rectification which is usually done using Process Failure Mode Effective Analysis (PFMEA).

A Process Failure Mode Effects Analysis (PFMEA) is a structured analytical tool used by an organization, business unit, or cross-functional team to identify and evaluate the potential failures of a process. PFMEA helps to establish the impact of the failure and identify and prioritize the action items with the goal of alleviating risk. It is a living document that should be initiated prior to process of production and maintained through the life cycle of the product. PFMEA is a standardized process that is followed globally to address the potential process failures by identifying and analysing the faults that occur due to incompetent processes that hamper the quality of the product.

PFMEA is done by organizations with cross functional team looking into every aspect of the process to identify the risks associated with the process and prioritize the process.

The work on the vertical component of PFMEA to reduce the data analysis of the issues and rectify a bigger spectrum in a shorter span by selectively targeting the 6M's was undertaken. This was done so as to reduce the data collection and the analysis time of the PFMEA process.

2. LITERATURE REVIEW

Having originated in the U.S. military in the 1940s, Failure Mode and Effect Analysis (FMEA) today is an analytical tool widely employed in approaches to quality like ISO 9000, ISO/TS 16949, Six Sigma, and Design for Six Sigma (DFSS) [1]. FMEA was first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements. Later, its use spread to other industries, such as the automotive, oil and natural gas. FMEA aims to identify and prioritize possible imperfections in products and processes. FMEA analyses: potential failure modes of product or machine, potential effects of failure, potential causes for failure (like material defects, design deficiencies),assesses current process controls, and determines the risk priority factor [9].FMEA is a systematic method of identification and preventing products and process' problems before it occurs. FMEAs focus on preventing defects, enhancing safety and increasing customer satisfaction. It is precisely an analytical methodology used to ensure that potential problems have been identified and addressed through the product and process development cycle [2].

The application of a PFMEA reveals the hidden process weaknesses, leading to the quantification of failure related indicators/failure risks and the creation of a prioritization matrix for further improvement actions. Risk reassessment and further preventive action planning could lead to effective risk minimization [3]. FMEA analysis may easily help in improving the efficiency of the manufacturing process and quality of product thus decreasing the number of defective products and saving of rework cost and time [4]. PFMEA is conventionally done with cross functional team members of different domains so that there is open ended approach while analyzing a process and determining the Risk Priority Number (RPN) [5]. Fishbone diagram is a method used to determine the global risk of an event with multiple relevant causes, relatively easy to apply. The application realized allows determining the risk of secondary and main causes, of cause's categories and of the global risk, allows structuring of treatment measures on vulnerability areas, precisely oriented on the causes which determine high risk values [6].

Causes are defined for the Failure Mode and should be determined for their impact on the Failure Mode being analyzed. Causes typically follow the Fishbone / Ishikawa Diagram approach, with the focus of cause brainstorming on the 6M's:

Man, Method, Material, Machine, Measurement and Mother Earth (Environment). Common uses of the Ishikawa diagram are product design and quality defect prevention to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify and classify these sources of variation.

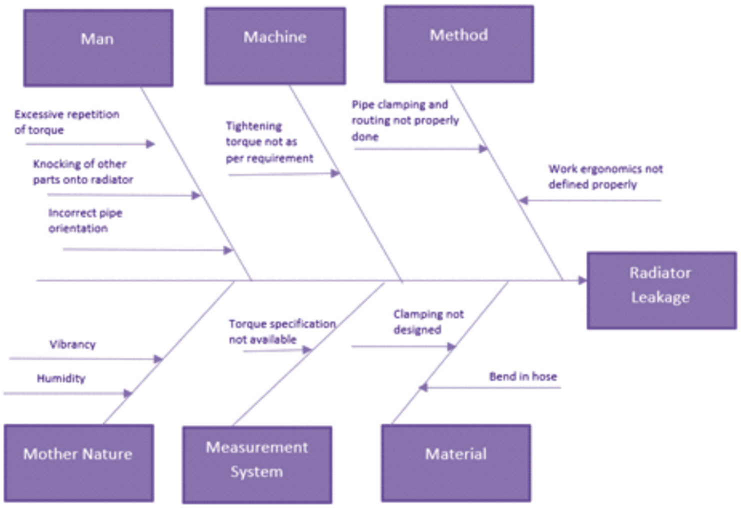

Figure 1 - Fishbone Diagram for example of Radiator Leakage

3. PFMEA

Process Failure Mode Effect Analysis is a technique that uses the knowledge of processes and the experience of people in identifying the probable failure mode of the process that may affect the entire manufacturing of the product. PFMEA charts the action to easily and inexpensively identify the probable adversities of the process in production and rectify them with the ideas from a cross functional, experienced team.

FMEA can be used as an individual project tool. However, it is strongly recommended that use to generate corrective action in a process improvement project. An FMEA is not a trivial tool rather it requires significant effort from a diverse team. FMEA method follows a standardized process that requires cautious selection of the team and unbiased outlook towards a process. The steps followed are:

- Identification of the cross-functional team
- Defining the scope of the PFMEA
- Defining the customer
- Identifying functions and requirements
- Identifying potential failure modes
- Identifying potential effects and causes
- Identifying controls and assessing risks
- Recommended actions and results

3.1. Methodology

The five major-defects PFMEAs were taken into consideration. In the current work the horizontal and the vertical data were interchanged. The steps followed were:

➢ The count of defects for each of the failure modes against the 6M were noted in the tabular form and calculated.

➢ M's were ranked according to the number of defects found. For each of the failure modes, the RPN (Risk Priority Number) was noted down vertically below each of the failure mode.

➢ These failure modes were ranked based on this RPN. After carrying out this procedure for all the PFMEAs, the top ranks of all the 6Ms versus the rank of the maximum RPNs were compared.

➢ The most prominent M that contributed to the RPN was obtained from this.

Taking into consideration the example of Radiator sub-assembly and fitment, error identification was carried out. This included analysing the entire processing right from the beginning and then finding out all the possible causes due to which there might be a failure in the process at a further stage. This was found out through brainstorming by a cross functional team and from the data of the past failures of that product at that stage (radiator, in this case).

Through this Error Identification Process, Human Errors, or Man in the 6M was obtained. The general human errors could be categorized in these 16 modes:

- Omission,
- Excessive / Insufficient repetition,
- Wrong order, Early / Late execution,
- Execution of restricted work,
- Incorrect Selection and Counting,
- Misrecognition,
- Failing to sense danger,
- Incorrect holding,
- Incorrect positioning,
- Incorrect orientation,
- Incorrect Motion,
- Improper Holding,
- Inaccurate Motion,
- Insufficient Avoidance.

All the errors are mapped to these 16 parameters for finding the Man-made errors.

	16 Error Modes	Place radiator on trolley	Place fan shroud on radiator	Engage the radiator and fan by matching the holes with the help of nut and bolts	Engage thermostat support break with help of nut and bolt
1	Omission	NA	NA	Operator may forget to insert nut and bolts at certain holes	NA
2	Excessive / Insufficient repetition	NA	NA	NA	NA
3	Wrong order	Operator may place radiator of different model	NA	NA	NA
4	Early / Late execution	NA	NA	NA	NA
5	Execution of restricted work	NA	NA	NA	NA
6	Incorrect Selection	Operator may select incorrect radiator	Operator may select incorrect fan shroud	Operator may select incorrect nut and bolts	Operator may select incorrect thermostat support break
7	Incorrect Counting	NA	NA	NA	NA
8	Misrecognition	NA	NA	Operator may misrecognize the nut bolts specifications	NA
9	Failing to sense danger	Operator may fail to sense radiator cores not to be approached	NA	NA	NA
10	Incorrect holding	Operator may hold radiator in incorrect way	Operator may hold shroud in incorrect way	NA	Operator may hold thermostat support break in incorrect way
11	Incorrect positioning	Operator may set radiator in wrong position	Operator may set shroud in wrong position	Operator may engage nut bolts in wrong position	Operator may set thermostat support break in wrong position
12	Incorrect orientation	Operator may set radiator in the wrong way around	Operator may orient shroud in the wrong way around	Operator may engage nut bolts in incorrect orientation	Operator may orient thermostat support break in the wrong way around
13	Incorrect Motion	NA	NA	NA	NA
14	Improper Holding	NA	Operator may fail to ensure that the shroud does not move	NA	Operator may fail to ensure that thermostat support break does not move
15	INAccurate Motion	NA	NA	NA	NA
16	Insufficient Avoidance	Operator may knock radiator on the trolley	Operator may knock shroud on the radiator	NA	Operator may knock thermostat support break on other parts

	16 Error Modes	Tighten these nuts with help of battery tool	Apply aNAbond to the inside of the radiator bottom hose	Fit radiator bottom hose on rubber hose metal pipe	Fit worm clip on joint
1	Omission	NA	Operator may forget to apply aNAbond	NA	NA
2	Excessive / Insufficient repetition	Operator may apply excessive torque	Operator may apply insufficient aNAbond	Operator may insufficiently fit the hose	Operator may insufficiently fit the clip
3	Wrong order	NA	NA	NA	NA
4	Early / Late execution	NA	NA	NA	NA
5	Execution of restricted work	NA	NA	Operator may fit defective hose	NA
6	Incorrect Selection	NA	NA	Operator may select incorrect hose	Operator may select incorrect clip
7	Incorrect Counting	NA	NA	NA	NA
8	Misrecognition	NA	NA	NA	NA
9	Failing to sense danger	NA	NA	NA	NA
10	Incorrect holding	Operator may hold battery tool in incorrect way	NA	Operator may hold hose in incorrect way	Operator may hold clip in incorrect way
11	Incorrect positioning	NA	NA	Operator may set hose in wrong position	Operator may set clip in wrong position
12	Incorrect orientation	NA	NA	Operator may set hose in wrong orientation	Operator may set clip in wrong orientation
13	Incorrect Motion	Operator may excessively tighten the nuts	NA	Operator may bend hose too much	Operator may give incorrect motion to clip
14	Improper Holding	Operator may fail to ensure that thermostat support break does not move	NA	Operator may fail to ensure that the hose does not move	Operator may fail to ensure that the clip does not move
15	INAccurate Motion	Operator may tighten bolts to INAccurate torques	NA	NA	NA
16	Insufficient Avoidance	Operator may place battery tool in slightly different position	NA	NA	NA

	16 Error Modes	Tighten these nuts with help of battery tool	Apply aNAbond to the inside of the radiator bottom hose	Fit radiator bottom hose on rubber hose metal pipe	Fit worm clip on joint
1	Omission	NA	Operator may forget to apply aNAbond	NA	NA
2	Excessive / Insufficient repetition	Operator may apply excessive torque	Operator may apply insufficient aNAbond	Operator may insufficiently fit the hose	Operator may insufficiently fit the clip
3	Wrong order	NA	NA	NA	NA
4	Early / Late execution	NA	NA	NA	NA
5	Execution of restricted work	NA	NA	Operator may fit defective hose	NA
6	Incorrect Selection	NA	NA	Operator may select incorrect hose	Operator may select incorrect clip
7	Incorrect Counting	NA	NA	NA	NA
8	Misrecognition	NA	NA	NA	NA
9	Failing to sense danger	NA	NA	NA	NA
10	Incorrect holding	Operator may hold battery tool in incorrect way	NA	Operator may hold hose in incorrect way	Operator may hold clip in incorrect way
11	Incorrect positioning	NA	NA	Operator may set hose in wrong position	Operator may set clip in wrong position
12	Incorrect orientation	NA	NA	Operator may set hose in wrong orientation	Operator may set clip in wrong orientation
13	Incorrect Motion	Operator may excessively tighten the nuts	NA	Operator may bend hose too much	Operator may give incorrect motion to clip
14	Improper Holding	Operator may fail to ensure that thermostat support break does not move	NA	Operator may fail to ensure that the hose does not move	Operator may fail to ensure that the clip does not move
15	INAccurate Motion	Operator may tighten bolts to iNAccurate torques	NA	NA	NA
16	Insufficient Avoidance	Operator may place battery tool in slightly different position	NA	NA	NA

	16 Error Modes	Tighten worm clip with battery tool	Fit LH and RH hoses with worm clip	Tighten worm clip with battery tool	Do the markings after correct fitment
1	Omission	NA	NA	NA	Operator may fail to do the markings
2	Excessive / Insufficient repetition	Operator may apply excessive torque	Operator may insufficiently fit the hoses	Operator may apply excessive torque	NA
3	Wrong order	NA	NA	NA	NA
4	Early / Late execution	NA	NA	NA	NA
5	Execution of restricted work	NA	Operator may fit defective hoses	NA	NA
6	Incorrect Selection	NA	Operator may select incorrect hose or clip	NA	NA
7	Incorrect Counting	NA	NA	NA	NA
8	Misrecognition	NA	NA	NA	NA
9	Failing to sense danger	NA	NA	NA	NA
10	Incorrect holding	Operator may hold battery tool in incorrect way	Operator may hold hose and clip in incorrect way	Operator may hold battery tool in incorrect way	NA
11	Incorrect positioning	NA	Operator may set hose in wrong position	NA	NA
12	Incorrect orientation	NA	Operator may set hose in wrong orientation	NA	NA
13	Incorrect Motion	Operator may excessively tighten the nuts	Operator may bend hose too much	Operator may excessively tighten the nuts	NA
14	Improper Holding	Operator may fail to ensure that worm clip does not move	Operator may fail to ensure that the hose does not move	Operator may fail to ensure that worm clip does not move	NA
15	INAccurate Motion	Operator may tighten bolts to iNAccurate torques	NA	Operator may tighten bolts to iNAccurate torques	NA
16	Insufficient Avoidance	Operator may place battery tool in different position	NA	Operator may place battery tool in slightly different position	NA

Figure 2 - Classification of Human Errors for Radiator Sub-Assembly

Later, the product characteristics and the failure modes where enlisted based on the expected and non-expected characteristics.

Determination Of Product Characteristics (Method 1)					
#	Operation / Station Description	What IS expected on the product (as this step)	What is NOT expected on the product (as this step)	Product Characteristics	Failure Mode
	Radiator Sub Assembly	Torque on clip	Pipe kink	Torque on clip	Excess / Insufficient torque on clip
		Proper addition of hose	Hose pipe twisted	Proper addition of hose	Improper addition of hose
		Correct orientation of hose	Hose pipe fouling	Correct orientation of hose	Incorrect orientation of hose
			Inclined clip	No dents on radiator	Dents on radiator
			Oozing out of shellac	Radiator free from corrosion	Corrosion of radiator
			Cut on hose	Proper fitment of radiator	Improper fitment of radiator
			Fins damage	Thermostat support break fitted properly	Thermostat support break not fitted properly
			Fins crack		
			Slug inside hose		
			Blowhole on hose joint		
			Wrong clip		
			Wrong routine		
				No kink on pipe	Pipe kink
				Hose pipe not twisted	Hose pipe twisted
				No fouling of hose pipe	Hose pipe fouling
				Proper fitment of clip	Inclined clip
				No oozing out of shellac	Oozing out of shellac
				No cut on hose	Cut on hose
				No damage of fins	Fins damage
				No crack on fins	Fins crack
				No slug inside hose	Slug inside hose
				No blowhole on hose joint	Blowhole on hose joint
				Correct clip	Wrong clip
				Correct routine	Wrong routine

Figure 3–Determination of Product Characteristics

In the case of radiator, the following failure modes were identified-

1. Excess / Insufficient torque on clip
2. Improper addition of hose
3. Dents and corrosion on radiator
4. Thermostat support break not fitted properly
5. Pipe kink
6. Hose pipe fouling
7. Inclined clip
8. Oozing out of shellac
9. Fins damage
10. Slug inside hose
11. Blowhole on hose joint
12. Wrong clip

The causes for the major defects of each of these PFMEAs were analysed through the 6M analysis. The 6M analysis includes Man, Machine, Method, Mother nature (Environment), Measurement system and Material. The 6M analysis had the description of failure modes noted vertically and the causes horizontally.

The determination of the failure modes of the operation was the starting point of the 6M analysis chart. These were noted vertically on the left-hand side of the chart. The 6Ms were written on the top horizontally; such that the causes due to each of these Ms could be noted across the failure modes. The arrangement is shown in Figure 4.

The Machine errors in this case of radiator sub-assembly were considered mainly due to the torque inaccuracies, so accordingly the causes for each of the failure modes were noted. And similarly, the other causes of other M's were tabulated in the same way.

				6M Analysis					
#	Operation / Station Description	Description of Failure Mode	#	Men	Machine	Method	Mother Nature (Environment)	Measurement System	Material
	Radiator Sub Assembly	Excess / Insufficient torque on clip		Excessive / Insufficient repetition	Battery tool faulty	Not followed process sheet,WIS	Operator working under fatigue	Torque specification not available	NA
				Inaccurate motion	Maintenance not	Process sheet not			
						Tool selection not			
						Work ergonomics not defined properly			
		Improper addition of hose		Incorrect Holding	Torque less applied	Battery tool not calibrated	NA	NA	Clamping not designed
				Incorrect Positioning		Blind operation of hose fitment			Bend in hose
		Dents and corrosion on radiator		Failing to Sense Danger	Knocking of battery tool or runner on	Rough handling	Vibrancy, Humidity	NA	Packaging inadequite for protection of
				Insufficient					
		Thermostat support break not fitted properly		Bolt kept loose by Operator	Torque less applied	Not followed process sheet,WIS	Operator working under fatigue	Torque not measured properly	NA
						Improper distribution of clamp pressure			
		Pipe kink		Pipe orientation is wrong	Tightening torque not as per requirement	Holding / clamping constraints not	NA	NA	High pressure on hose
						Pipe clamping and routing not properly			Pipe not as per spec

				6M Analysis					
#	Operation / Station Description	Description of Failure Mode	#	Men	Machine	Method	Mother Nature (Environment)	Measurement System	Material
		Hose pipe fouling		Insufficient Avoidance	Tightening torque not as per requirement	Hose pipe vibration	Surface moistured/unclean	NA	Wrong part fitted
				Incorrect orientation					
		Inclined clip		Improper fitment of clip by operator	Tightening torque not as per requirement	Process not followed	NA	NA	NA
		Oozing out of shellac		Excessive quantity taken by operator	NA	No specific guidelines	NA	Visually check	Viscosity
		Fins damage		Knocking of other parts onto radiator	NA	Process sheet not followed	Moisture	NA	Improper material
				Operator may fail to sence the radiator fins not to be			Dusty surroundings		
		Slug inside hose		Excessive quantity taken by operator	No machine available for quantity	No specific guidelines	NA	Visually check	Viscosity
		Blowhole on hose joint		Incorrect pipe orientation	Tightening torque not as per requirement	Not followed process sheet,WIS	NA	NA	High fluid pressure on hose joint
						Rough handling			
		Wrong clip		Misrecognition by the operator	NA	Misreading process sheets / WIS	NA	NA	Incorrect selection

Figure 4 - 6M Analysis for the operation

After the 6M chart was made, the horizontal and vertical data was swapped. The tables were swapped as the data needs to be analysed according to the factors in the chart. By transforming the rows and column, we get the failure data for individual points in the chart. This will help in substantially reducing the further analysis of the data and reduction in the RPN by finding the common failure modes. Taking the action on the common data will reduce the efforts of analysis, man power and efforts to classify each and every defect.

Then, for the failure modes, the count for each of the failure modes for each M was tabulated.

For example, excess torque on clip, the total defects due to Men were 2, due to Machine- 2, due to Method- 4, due to Mother nature- 1, and due to Material- 0. The total defects for the Radiator sub-assembly for the M's were as follows:

Table 1 - Failure Mode occurrence from 6M Analysis for “excess torque on clip”

Cause of Defect	Total Occurrences
Man	2
Machine	2
Method	4
Mother Nature	1
Measurement Systems	0
Material	0

Similarly, the counts for each of the defects were found. The occurrences are listed below

Table 2 - Total failure mode occurrence from 6M Analysis for all the defects

Cause of Defect	Total Occurrences
Man	17
Machine	10
Method	19
Mother Nature	6
Measurement Systems	4
Material	11

Consequently, these were ranked and it was found out that Method contributed the most to the number of defects.

Next, the RPNs for each of the failure modes were listed from the PFMEA chart, as follows:

Table 3 - Risk Priority Number(RPN) for each process failure

Process Failure	RPN
Excess / Insufficient torque on clip	112
Improper addition of hose	54
Dents and corrosion on radiator	112
Thermostat support break not fitted properly	60
Pipe kink	48
Hose pipe fouling	72
Inclined clip	72
Oozing out of shellac	4
Fins damage	28
Slug inside hose	20
Blowhole on hose joint	96
Wrong clip	112

Further, these modes were ranked based on RPN. Thus

1. Excess / Insufficient torque on clip
2. Dents and corrosion on radiator
3. Wrong clip

Were found to be most critical defect and Method was found to be highest contributing factor among the 6 M's.

Table 4 - RPN with their Rankings for each process failure

	Radiator Sub Assembly					
	Excess / Insufficient torque on clip	Improper addition of hose	Dents and corrosion on radiator	Thermostat support break not fitted properly	Pipe kink	Hose pipe fouling
Men	2	2	2	1	1	2
Machine	2	1	1	1	1	1
Method	4	2	1	2	2	1
Mother Nature	1	0	1	1	0	1
Measurement	1	0	0	1	0	0
Material	0	2	1	0	2	1
RPN	112	54	112	60	48	90
Rank	1	8	1	7	9	5

	Radiator Sub Assembly					
	Inclined clip	Oozing out of shellac	Fins damage	Slug inside hose	Blowhole on hose joint	Wrong clip
Men	1	1	2	1	1	1
Machine	1	0	0	1	1	0
Method	1	1	1	1	2	1
Mother Nature	0	0	2	0	0	0
Measurement	0	1	0	1	0	0
Material	0	1	1	1	1	1
RPN	72	4	28	20	96	112
Rank	6	12	10	11	4	1

This process clearly showed that if the Method of the processes are rectified, The RPN of the system could decrease by a good amount of all the processes.

E.g.

1. The process for wrong clip selection was changed. Dedicated bins were utilized to inspect the clip size before the process so that the defect does not pass on to the customer.
2. Green marking started at hose clip after tightening done with torque control battery tool to verify fitting of the clip to avoid the inclination.

Table 5 - Comparison between Old RPN and New RPN

Process Failure	RPN(old)	RPN(new)	% improvement
Excess / Insufficient torque on clip	112	64	42.86%
Improper addition of hose	54	54	0.00%
Dents and corrosion on radiator	112	80	28.57%
Thermostat support break not fitted properly	60	60	0.00%
Pipe kink	48	48	0.00%
Hose pipe fouling	90	72	20.00%
Inclined clip	72	36	50.00%
Oozing out of shellac	4	4	0.00%
Fins damage	28	28	0.00%
Slug inside hose	20	20	0.00%
Blowhole on hose joint	96	96	0.00%
Wrong clip	112	16	85.71%

4. CONCLUSION

Table 6 compares the data for PFMEA of radiator sub assembly before the vertical analysis and after the vertical analysis. The table clearly shows that most of the failure modes have shown a tremendous reduction in the RPN. This is mainly due to the classification of common failure modes and acting on them. This not only reduced the tedious task of calculating the RPN for individual failures but also reduces the data work associated in collecting and analysing the same.

This paper aimed at the vertical component of PFMEA to reduce the data analysis of the issues and rectify a bigger spectrum in a shorter span by selectively targeting the 6M's. This paper utilises simple ranking process based on the number of defects with respect to each of the M's and using the RPN. Vertical PFMEA will help in simplifying the PFMEA process and thus scores a greater value than the standard process.

5. FUTURE SCOPE

The work presented in this paper can be further cemented by quantification of the value using the cost inputs at each process. The misalignment of the process with the laid criteria could be judged and found out by calculating the costs at each step both before and after. The cost should ideally decrease since all the issues pertaining to one factor are of the 6 M's are attacked simultaneously reducing the work cost as well as the process cost besides reducing the losses incurred to organisation due to faulty process parameters.

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