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Prediction of Defects in Axle Production Using Monte-Carlo Simulation

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Abstract:*The automotive industry in India is one of the largest in the world. India is also a prominent auto exporter and has strong export growth expectations for the near future. Like companies in all sectors of manufacturing, automobile manufacturers face unique challenges that they must address in order to create long-lasting success. There are particular field which holds special significance for automobile manufacturers. Quality improvement/management is one of them and that has to be addressed properly, because the automotive industry has many to answer. Consumers and their safety in vehicles is not to be taken lightly. Time & cost are the prime factors that completely depends on quality of product. In this study,pareto with the help of Monte Carlo Simulation will help save time and effort ofthe inspection department by predicting the occurrence of defects, which reflects on costs as well.*

Keywords*-Prediction, Monte Carlo Simulation, Pareto, Axle Production*

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I. Introduction

Indian auto industry is one of the largest in the world. The industry accounts for 7.1 per cent of the country's Gross Domestic Product (GDP). The four Wheelers segment with very high per cent market share is the leader of the Indian Automobile market owing to a growing middle class and a young population dynamics of the country. Moreover, the growing interest of the companies in exploring the rural markets further aid the growth of the sector. The overall Passenger Vehicle (PV) segment has 14 per cent market share.

India is also a prominent auto exporter and has strong export growth expectations for the near future. Overall automobile exports grew 15.81 per cent year-on-year between April-February 2017-18. In addition, several initiatives by the Government of India and the major automobile players in the Indian market are expected to make India a leader in the 2W and Four Wheeler (4W) market in the world by 2020.

Automobile manufacturing is an iconic form of Indian manufacturing that has been an integral part of the economy ever since the invention and popularization of the automobile itself. Today, the automobile industry remains highly important–and the small and medium-sized auto manufacturers now play a more important role than ever.

Quality improvement/management is cardinal for the automotive industry, because the automotive industry has the safety of its users in its hands. Consumers and their safety in vehicles is not to be taken lightly. Safety is of the utmost importance and a quality management system is an important way for vehicles and their parts to pass safety tests and standards. Total Quality Management (TQM) describes the culture, attitude, and organization of a company striving to produce high quality products and services that meet or exceed customer expectations. The following are reasons that quality management is growing in importance in the automotive industry.

Timing

By utilizing quality management systems, it is easier to get products on the market faster. If there are problems with quality or consistency of parts, it can slow down the whole process. Quality management systems can help to bypass this issue. In addition, introducing products to the market quicker than your competition can be a lucrative tactic.

Costs

Improvement of the quality of your products can lower costs. Think of all the money wasted in producing parts that don't meet quality standards such as costs of goods, labour, or pricey recalls. Then, think of how easily that can be eliminated by exercising quality management.

The production of axles is a complex process. There are many operations that have to be performed for the complete assembly of the axle. Firstly, the assembly of the stub axle is done followed by the mounting and fastening of the brakes. After this, the wheel hub, brake actuator, brake drum, and tie rod are installed. Finally, the ABS cable is fitted followed by the painting operation. However, inspection is a key task in the automotive industry,

In this complete process, there are five gates or stages for the inspection of the produced parts namely Beam, Conveyor, Testing, and Ass Buy Off. In each of the five gates combined, there are more than 240 defects that can occur. Some defects are- air leakage from Dowell pin, R.A Shaft wrong, Case cover machining not ok, High point, pole wheel damage, Hand brake cable damage, ABS cable damage, etc. Hence, this is an enormous task that requires huge man power and time for the completion of the same. This in turn, reduces the productivity of the operation, increasing the costs and reducing the efficiency of the entire process.

The work presented in this paper tries to take into account these problems and gives a probable solution.

II. Literature Review.

Quality management is an important strategy for companies to utilize to ensure quality and consistency. Quality management is comprised of quality planning, control, assurance and improvement. Although Henry Ford played an integral part in introducing quality management into how he ran his assembly lines, the utilization of quality management is growing even more important now (especially in the automotive industry). In modern industrialization quality control is a concept which requires that every product be checked against established standards to make sure that nothing defective reaches to the consumer. It has quietly transformed manufacturing in India. Based in large part on statistics and the theory of probability, quality control can cut costs and improve product performance and reliability at the same time. Thus it benefits the consumer as well as the producer.

At the same time organization also take care of that they don't overdo quality control practice. In this case study on each gate there are number of quality checks which were not been used that often. That arises to lots of time and indirectly cost wastage.

The problem faced by organization while doing their regular practice are as follows:

1. Theproduction process for axle generates many defects which ultimately result in loss of production and higher costs.
2. Inspection is carried out at five gates or stages. Hence, the process is cumbersome and extensive man power is required for the same.
3. There are certain defects that are critical while some which could be corrected through rework. The occurrence of each defect is also different, making the inspection process quite complex.
4. There is no method to predict as to when a certain defect might occur. Hence, each and every part has to be inspected. This takes a lot of time, reducing the efficiency.

The objective of this study is to overcome all above mentioned problems. There are many actions required to ensure the effective quality management at unnecessary cost and time. A systematic study is carried out to identify and reduce these defects.

1. Firstly, a systematic approach was adopted to find out the most critical defects out of the total defects. The occurrence, criticality, etc. of each of the defects was considered for finding out the same. Pareto analysis helped in classifying the defects in various categories.
2. Secondly, Monte-Carlo Simulation was used to forecast the occurrence of the most critical defects found earlier.

Pareto analysis is a formal technique useful where many possible courses of action are competing for attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective actions that deliver a total benefit reasonably close to the maximal possible one. While it is common to refer to Pareto as "80/20" rule, under the assumption that, in all situations, 20% of causes determine 80% of problems, this ratio is merely a convenient rule of thumb and is not nor should it be considered immutable law of nature. The application of the Pareto analysis in quality management allows management to focus on those higher priority checks that have the most impact on the project.

Being a huge established organization, they follow their standard quality procedure. As a result, that arises to above mentioned problem. Pareto will help in finding highest priority defects from each gate. Monte Carlo simulation will help in simulating defects on each day, while comparing with actual one will get exact error.

Risk analysis is part of every decision we make. Industries are constantly faced with uncertainty, ambiguity, and variability. And even though they have unprecedented access to information, industries can't accurately predict the future. Monte Carlo simulation (also known as the Monte Carlo Method) help them to see all the possible outcomes of their decisions and assess the impact of risk, allowing for better decision making under uncertainty.

Monte Carlo simulation is a computerized mathematical technique that allows industrial personal to account for risk in quantitative analysis and decision making. The technique is used by professionals in such widely disparate fields as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation, and the environment. Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action. It shows the extreme possibilities—the outcomes of going for broke and for the most conservative decision—along with all possible consequences for middle-of-the-road decisions.

The technique was first used by scientists working on the atom bomb; it was named for Monte Carlo, the Monaco resort town renowned for its casinos. Since its introduction in World War II, Monte Carlo simulation has been used to model a variety of physical and conceptual systems.

Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values—a probability distribution—for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. Monte Carlo simulation produces distributions of possible outcome values. By using probability distributions, variables can have different probabilities of different outcomes occurring. Probability distributions are a much more realistic way of describing uncertainty in variables of a risk analysis.

III. Methodology

i. Pareto Analysis: -

There are more than 240 types of defects that occur in different stages during the production of axles. These stages or gates are- Beam, Conveyor, Carrier, Testing, and Assembly Buy Off. The data comprised of the daily inspections and defects that occur during the production of axles. The timeline of the data was of 10 months. For each of the five gates, pareto (80-20) analysis was carried out for the data over 9 months. The remaining one month's data was used to test the results which would have gathered by the application of Monte-Carlo simulation. The result of the pareto analysis was as follows.

1) Assembly Buy Off: -

S no.	Defects	No. of defects occuring over 9 months	%age	Cumulative Percentage
1	Rubber gromet missing	100	12.42236025	12.7064803
2	Number plate not fitted	53	6.583850932	19.29033124
3	Drum jam	48	5.962732919	25.25306416
4	R.A. cover bolt not fitted	45	5.590062112	30.84312627
5	ABS not ok/ABS not checked	42	5.217391304	36.06051757
6	Hand brake cable damage	46	5.714285714	41.77480329
7	Drain/ feeler plug spoiled	37	4.596273292	46.37107658
8	C' clamp wrong	36	4.472049689	50.84312627
9	Chamber position wrong	30	3.726708075	54.56983434
10	ABS Cable damage	26	3.229813665	57.79964801
11	Dust cover damage	32	3.97515528	61.77480329
12	Axial play not ok	27	3.354037267	65.12884055
13	Hub play record missing on history card	26	3.229813665	68.35865422
14	No hub play record	24	2.98136646	71.34002068
15	Circlip and shim missing/circlip not fitted properly	18	2.236024845	73.57604552
16	Adaptor wrong	15	1.863354037	75.43939956
17	A/P Bolt loose	15	1.863354037	77.3027536
18	A/P plumber block bolt loose	15	1.863354037	79.16610763
19	Painting not ok	13	1.614906832	80.78101447

Table 1- Ass Buy Off Pareto Analysis

2) Testing-

S no.	Defects	No.	%age	Cum
1	Drum jam	72	21.17647	21.17647
2	High point	66	19.41176	40.58824
3	ABS air gap	40	11.76471	52.35294
4	Pinion overheated ???	30	8.823529	61.17647
5	wrong Axle	21	6.176471	67.35294
6	Pole wheel damage	8	2.352941	69.70588
7	ABS run out	6	1.764706	71.47059
8	Drum noise	5	1.470588	72.94118
9	differential noisy	4	1.176471	74.11765
10	air leakage not found	4	1.176471	75.29412
11	diff noise on reverse side	4	1.176471	76.47059
12	Feeler plug sleep	4	1.176471	77.64706
13	differential jam	3	0.882353	78.52941
14	slack Adj. circlip not fitted properly.	3	0.882353	79.41176
15	A/P One bolt loose	3	0.882353	80.29412

Table 2- Testing Pareto Analysis

3) Carrier-

S No.	Defects	No.	%age	Cum
1	crown pinion hardness not ok	21	29.57746	29.57746
2	Case cover face spot facing not ok	18	25.35211	54.92958
3	pinion lock tapping not done	5	7.042254	61.97183
4	Pinion lock missing	4	5.633803	67.60563
5	Case cover face machining not ok	3	4.225352	71.83099
6	LCRV bracket not in position	3	4.225352	76.05634
7	Pinion dust cover loose	3	4.225352	80.28169

Table 3- Carrier Pareto Analysis

4) Conveyor-

S no.	Defect	No.	%age	Cum
1	Air leakage not found	117	33.33333	33.33333
2	No plate not fitted	29	8.262108	41.59544
3	Rubber grommet missing	18	5.128205	46.72365
4	Number plate wrong	15	4.273504	50.99715
5	No hub play record	13	3.703704	54.70085
6	Anchor plate pin loose	11	3.133903	57.83476
7	Adaptor wrong	10	2.849003	60.68376
8	No history card	8	2.279202	62.96296
9	Shaft bolt not fitted properly	8	2.279202	65.24217
10	R.A. Shaft wrong	8	2.279202	67.52137
11	Hub tapping for shaft not ok	7	1.994302	69.51567
12	Rubber grommet not properly fitted	7	1.994302	71.50997
13	drain plug sleep	7	1.994302	73.50427
14	Hand break cable damage	7	1.994302	75.49858
15	Anchor plate mounting bkt bolt not fitted	6	1.709402	77.20798
16	Nylock nut not fitted	6	1.709402	78.91738
17	Anchor plate nut loose	6	1.709402	80.62678

Table 4- Conveyor Pareto Analysis

5) Beam-

S no.	Defects	No.	%age	Cumulative
1	Air leakage from dowell pin	17	54.84	54.84
2	Saddle unclean	7	22.58	77.42
3	Mark on RA hsg cover face	2	6.45	83.87

Table 5- Beam Pareto Analysis

Hence, by the application of Pareto analysis, most contributing defects were identified. Further, classifications is done to curtail down the number of defects for simulation. A 3-point strategy was devised for the same. First, all the defects were categorized into two major categories, i.e. whether the defect causedrejection of the part or whether was it sent to rework. Therefore, only the defects causing rejections were considered for further analysis.

Second, a further classification was done, stating whether the defect was an in-house manufacturing defect or a supplier defect. For this study, only the in-house manufacturing defects were considered to particularly focus on a strategy to improve the same. Third, only those defects were considered for further analysis whose average was more than 1 per month.

Therefore, Monte-Carlo Simulation was applied to the following defects- Hand Brake Cable Damage (Ass Buy Off), ABS Cable Damage (Ass Buy Off), Dust Cover Damage (Ass Buy Off); Air Leakage (Conveyor); High Point (Testing). Hence, the gates- Beam & Carrier got dissolved.

ii. Monte-Carlo Simulation-

To set up the simulation, data of the first 9 months, i.e. from Apr'17 to Dec'17 was used. The remaining one month's data was used to test the simulation. This resulted in the data points being around 230 in number. Hence, to set up the simulation 5-6 classes were considered for each of the defects. Consider the frequency distribution table for the defect "Hand Brake Cable damage".

Class	Mid Class Value	Frequency	Cumulative Frequency	Percentage	Cdf
0 to 1	0.5	186	186	82.30088496	82.30088496
1 to 2	1.5	37	223	16.37168142	98.67256637
2 to 3	2.5	2	225	0.884955752	99.55752212
3 to 4	3.5	0	225	0	99.55752212
4 to 5	4.5	0	225	0	99.55752212
5 to 6	5.5	1	226	0.442477876	100

Table 6- Cdf for the defect"Hand Brake Cable Damage "

The frequency of the classes defines the number of defects that occurred during the course of the 9 months, which follows the lower bound rule. This sets up the simulation between cdf and mid class values as follows.

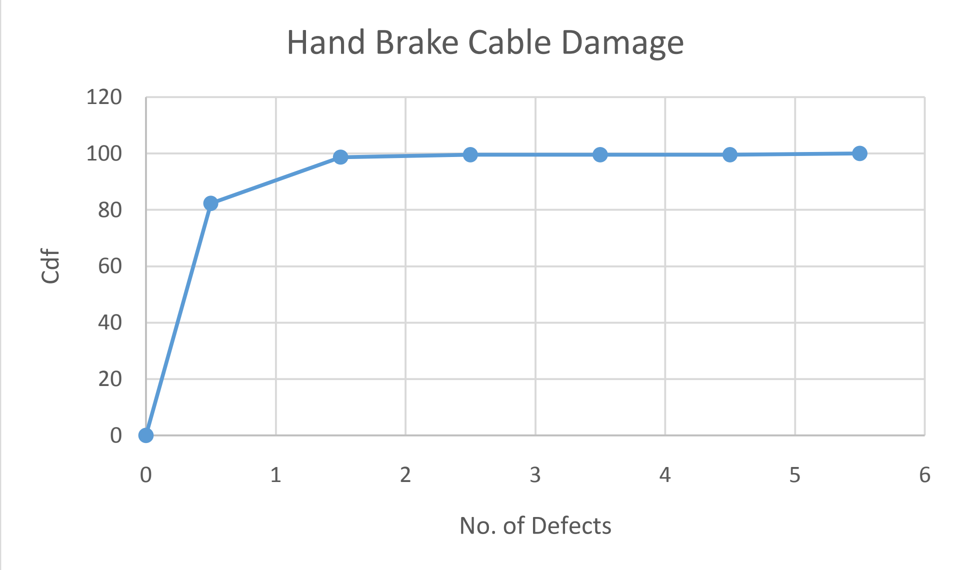

Figure 1- Simulation Set up for Hand Brake Cable Damage

Further,random numbers corresponding to the number of inspection days in Jan'18 were generated for each gate, and were further projected on to the graph to find the x values. It is extremely important to note that in this simulation, the final x value is 0 if the corresponding value lies between [0,1). Similarly, the x value is 1 if the corresponding value lies between [1,2) and so on.

IV. Results-

The results indicate the simulated defects vs the actual defect, for each type of defect as follows.

ASS BUY OFF	Hand Brake Damage			Abs Cable Damage			Dust Cover Damage		
Day	R Nos	Sim	Act	R nos	Sim	Act	R No.	Sim	Act
1	69	0	0	71	0	0	36	0	0
2	76	0	0	74	0	0	55	0	0
3	83	0	0	57	0	0	26	0	0
4	1	0	0	37	0	0	82	0	0
5	92	1	0	0	0	0	20	0	0
6	36	0	0	56	0	0	98	1	0
7	71	0	0	34	0	0	69	0	0
8	18	0	0	74	0	0	14	0	0
9	67	0	0	23	0	0	79	0	0
10	52	0	0	31	0	0	63	0	3
11	26	0	0	49	0	0	96	1	0
12	31	0	0	90	0	0	27	0	0
13	38	0	1	73	0	0	69	0	0
14	83	0	0	66	0	0	14	0	0
15	57	0	0	21	0	0	11	0	0
16	98	1	0	38	0	0	39	0	0
17	36	0	0	62	0	0	6	0	0
18	86	0	0	61	0	0	3	0	0
19	85	0	0	76	0	0	47	0	0
20	94	1	1	53	0	0	7	0	2
21	41	0	1	80	0	0	46	0	0
22	17	0	0	87	0	0	95	1	0
23	11	0	0	19	0	0	76	0	0
	Sum	3	3	Sum	0	0	Sum	3	5

Table 7- Simulated vs Actual (1)

	Air Leakage (Conveyor)			**High Point (Testing)**		
Day	R No.	Sim	Act	R No.	Sim	Act
1	59	0	0	59	0	0
2	76	1	0	43	0	0
3	21	0	3	55	0	6
4	16	0	0	44	0	0
5	92	2	0	21	0	0
6	52	0	0	100	4	0
7	50	0	0	39	0	0
8	15	0	0	51	0	0
9	34	0	0	39	0	0
10	16	0	0	47	0	0
11	16	0	0	40	0	0
12	32	0	0	4	0	0
13	80	1	0	73	0	0
14	9	0	1	86	0	1
15	82	1	2	19	0	0
16	76	1	0	26	0	0
17	13	0	0	97	2	0
18	19	0	0	87	1	0
19	9	0	2	2	0	2
20	70	0	0	89	1	0
21	70	0	0	91	1	3
22	29	0	0	84	0	1
23	19	0	2	23	0	0
24	94	2	0	24	0	0
25	29	0	0	25	0	0
26	12	0	0	26	1	0
	SUM	**8**	**10**		**10**	**13**

Table 8-Simulated vs Actual (2)

V. Conclusion

The primary purpose of the work presented in this paper is to reduce the inspection time of the automotive industry in order to save the time, cost and human resources associated with it.

There is a common notion in the research community that simulation should be used as the last resort when all other techniques fail. This is because, simulation doesn't provide the exact solutions, however, it can give an approximate solution.However, providing a range of values for which an event can occur can be extremely valuable to the automotive industry as it will reduce the time, cost and human work considerably.

An error is defined as a day whose simulated value couldn't predict the actual value except 0. It is extremely important to note that if the simulated value resulted in particular value except 0, where in, the actual value was 0, the error will be 0 as there was no faulty part gets used. Only the inspection increases.

The range is defined as the number of days before and after the simulated day on which a defect is expected to occur. For instance, if a simulated value is showing a defect to occur on the 10^{th} of Jan, the range "+-1" will consider for defects occurring on the 9^{th} and 11^{th} of Jan respectively as well. Hence, if an actual defect occurred on either of the days, the error will be 0, as it was rightly predicted. Therefore, for a higher range, inspection will increase as more number of days will have to be inspected with respect to the simulated value, however, the mean error will reduce.

The final result is as follows. There is no ideal solution to the problem. A company can use any of the results based on their capability and requirements.

Range	Mean Error	Percent Inspection Saved
+-0	20.7 %	85.12%
+-1	9.9%	62.81%
+-2	8.3%	46.28%
+-3	0	36.36%

Table 9- Final Results

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