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Eliminating end-of-line rejections – a quality filter mapping approach

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Abstract: Growing production volumes and high-quality requirements are some of the main challenges faced by manufacturing industries today. End of line rejections and rework contribute towards increasing the component costs, which in turn affects the customer pricing or company profits. The workaround created due to rework increases the complexity of flow and contributes to the hidden factory. This paper elaborates a step-by-step approach using a case study to develop a quality filter mapping for an engine assembly line which eliminates end-of-line rejections and rework. A pareto analysis reveals the vital few defects that are occurring along the assembly line. The root causes of these defects are identified using a cause-and-effect diagram and are mapped along material flow in the assembling plant. The quality filter map can be used to integrate quality control into the process flow and thereby prevent the flow of defectives in assembly and manufacturing lines.

Keywords: quality filter mapping; defect mitigation; step-by-step approach; assembly line.

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1 Introduction

Recent developments driving manufacturing industry trends are heavily influenced by changing customer requirements, product variances and fluctuating order volumes (Haefner et al., 2014). Increasing volumes in production and increased quality requirements pose complex challenges in assuring quality (Forno et al., 2014). To tide over these manipulating factors that affect a company's performance and growth, efficient and flexible approaches have to be adopted to optimise the flow of product information, starting from arrival of material to shipping of finished goods (Stadnicka and Litwin, 2019; Singh et al., 2011). Therefore, companies have to constantly innovate and improve their manufacturing system's economic efficiency, customer order fulfilment time and quality to remain relevant in the changing dynamics of the competitive world. These challenges (Mandal, 2021) complicate the waste identification process, lead to misinterpretations and assessment mistakes, and also undermine the implementation of strategic improvements. Verma et al. (2021) says delineating areas in need of improvements from the perspective of manufacturing competency or customer sensitivity can tend to be a labourious task if stringent quality control checks are not carried out in a manufacturing or assembly line, to eliminate defects in the product before it reaches the customer (Klimecka-Tatar, 2017).

These quality checks are done using quality control tools (Husain et al., 2021; Hines and Rich, 1997) either independently or in combination based on the different wastes inherent in value streams (Stadnicka and Litwin, 2019; Grigoryan and Golubkova, 2020). These tools prove to be instrumental in the decision-making process and they can also be helpful in developing activities prior to manufacturing, in measuring process variability, in analysing this variability relative to product requirements or specifications, and in eliminating or greatly reducing variability in the process. Further these tools also highlight the types of waste to be removed and identifies parts or components to be rejected or reworked. These parts are then processed in the appropriate process steps to ensure compliance with the customer specifications. This brings to light an age-old problematic process flow followed by many manufacturing and business organisations for ensuring excellence (Yarrow, 2000).

The main issue in defect localisation or identification is that they arise as a post-production process. Inspection can be performed at the EOL inspection or as an in-line inspection. Time and again, EOL inspection techniques have proved to be useful in assessing product performance post-manufacturing (Gehin et al., 2008). With EOL inspection techniques, companies can redirect their measures and efforts to suitably align their interests with that of the customer expectations and also make necessary modifications to their manufacturing line, that will help them come up with a manufacturing plan that is congruent with the values and preferences of customers. If a defect is caught in the EOL inspection, then a workaround is created to remove it from the manufacturing/assembly line and then the necessary fixturing is carried out to place it back on the line defect-free. The cost incurred in rework operations is included in the customer cost. This workaround and rework are kept hidden from the customers and hence is called as the hidden factory.

Inline inspection techniques implement suitable integral measures to identify defects in the manufacturing line. These can be immediately corrected before passing it down the line. We can ensure better quality and reliability of products, as this technique helps in improving the efficiency of production by eliminating wastefulness created during production processes whilst maintaining a profitable margin (Yarrow, 2000). But there are inherent drawbacks in this approach also. Inline inspections create stagnations at each machine with additional inspections, but helps in passing only quality products downstream (Al-Doori, 2021). But it also will be able to only identify rejections and rework and create a workaround.

The objective of this paper is to conduct a study to analyse an engine assembly line and develop a QFM to reduce rejection/rework of components. This paper gives the academic researchers as well as practitioners, a simple step-by-step approach to systematic elimination of defects in a real-time environment. Through this case study, they will be able to understand and apply this concept in any manufacturing industry. The concept of hidden factory is discussed in Section 2.1. The process flow, as detailed in Section 2.2, has to be mapped to understand the production line. The concept of QFM , a variation of value stream mapping, where the causes of the defectives are to be mapped to the value stream is discussed in Section 2.3. The process failure mode and effects analysis is used to reduce the defects and is discussed in Section 2.4. The steps in the development of QFM are detailed in Section 3 with a case study. The results and discussion of the case study are detailed in Section 4. The conclusions drawn are discussed in Section 5.

2 Literature review

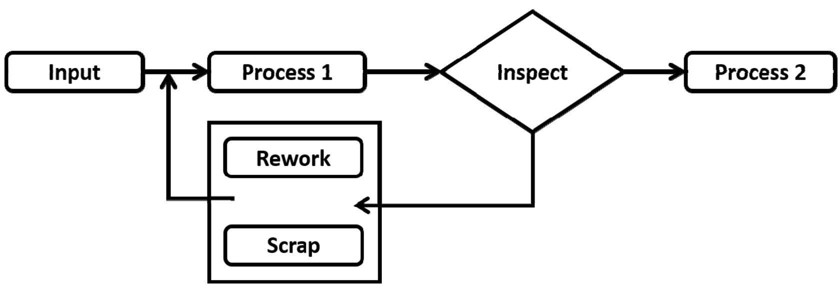
There is a vast literature on quality assurance, lean manufacturing concepts and detailed descriptions of each of the lean tools and techniques. The concept of value stream mapping to assess and streamline the process flow and its implementation has been studied through numerous case studies (Meudt et al., 2017). The quality of products along the line of production, integrating the testing processes, reducing the lead time in complex production environments and examining the challenges present in carrying out the necessary tasks with precision and accuracy have been studied in detail. Analysing the hurdles in implementation of the tools, we can get an overall picture of the areas that are in dire need of improvement from the perspective of production and control processes (Chandran and Saleeshya, 2020).

When product defects are analysed, mostly, immediate solutions for a particular problem or defect are looked out for. With the current understanding of quality improvement through six-sigma process improvements as well as finding the root cause of defects through lean tools, defect management has become more sophisticated (Raghuram and Saleeshya, 2021). But there are obstacles to implementing these tools. Once the obstacles in implementing these tools (Srinivasu et al., 2011) are overcome, then root causes can be effectively detected to indicate which causes, processes, setups and material properties affect a product quality and the process efficiency (Saleeshya and Thomas, 2019; Raghuram et al., 2017). Improvement of a process is based on predicting results caused by introducing changes in process, changes that happen when we modify the processes, that allows us to select the process methodology, bounds of the variables, techniques used, best organisation of the process, arrangement of the workplace and the process parameters.

2.1 Hidden factory approach

The 'Hidden Factory' is a term that may not be used in practice, but is present in all production shops. It refers to activities in an operation or standard operating procedure (SOP), which when employed could correct various errors that occur during various stages of the production process (Haefner et al., 2014: Czabak-Górska and Lorenk, 2017). A few examples of hidden factories are workarounds, rework, or any of the seven wastes. However, it is known that hidden factories increase the final cost of the product (Oberhausen and Plapper, 2015) mainly due to the lack of awareness of the phenomenon, as these operations are considered as part of SOP. Most companies maintain a hidden factory and you should be able to understand the processes that create these wastes and understand them in their manufacturing and services. These hidden factories can be a substantial drain on the bottom line, top line, on employee morale, shareholders and, most importantly, the customer.

Figure 1 Hidden factory



The term 'hidden factory' refers to all processes, activities, and systems that are not 'right first time'. Also, it is inferred that savings (Pud and Naik, 2012) obtained by the reduction of the costs connected with the 'hidden factory' are directly proportional to the savings from six sigma projects (Czabak-Górska, 2017). It is a process in which rework and non-value additions exist. Hence cleaning this area could enhance the production process by significantly reducing the unnecessary cost of poor quality (COPQ). Tangible issues of COPQ are rework, rejections, scrap, warranty costs, setup costs, inventory costs, delay costs, rework costs, WIP inventory and sales lost. Figure 1 describes the hidden factory. As the product moves from process 1 to process 2, it goes through inspection. If found to be 'OK', it passes onto the next operation.

Otherwise, there are two possibilities, viz., it may be defective, i.e., it has to be scrapped, or, it can be reworked in a prior process and corrected. These 'to be reworked' parts are then categorised according to the prior process in which corrections should be made, the respective fixtures carried to the machines along with these parts for setting it up again so that these parts can be corrected. If the defectives are checked only at the EOL inspection, the processes it went through become completely wasted, along with the part. The unrequired steps in manufacturing have to explicated so that the additional cost and time required for processing can be mitigated by taking subsequent steps in line with hidden factory procedure.

2.2 Value stream mapping

A value stream map (VSM) is a production planning and management tool which gives a graphical representation of flow of material and information in a production process (Miya and Ngacho, 2017; Nawcki et al., 2021). A VSM graphically represents all the processes involved in the operations taking special care to map out the value adding actions along a particular timeline and hence helping the reader to instantly identify the amount of time spent in non-value-added activities (Abdulmalek and Rajgopal, 2007; Mohammed, 2021). Value stream is defined as a mapping of all activities that happen in the process flow, both value-added and non-value-added, that are required to manufacture the product from raw materials till it reaches the customer (Lummus et al., 2006; Rother and Shook, 2003). This mapping mainly aims at identifying all the types of wastes which exist in a value stream and thereby helps us take steps towards reducing or eliminating them (Nguyen and Chinh, 2017). Simple, yet logical representations of the process are used to document both the current state and the future state (Dadashnejad and Valmohammadi, 2018). The current state map gives the state of existing activities. It helps us to see associated problems in material and information flow. From this, we can note down actions to be taken and improvements that can be effected. The future state map gives the visualisation of the proposed process flows after making the improvements.

V.S.M. can enable all partners along the process flow including employees at all levels as well as the customers to distinguish between value added activities and non-value-added activities. VSM creates a common basis for the production process, thereby facilitating more thoughtful decisions to improve the value stream (Abdulmalek and Rajgopal, 2007). Emerging to be one of the most preferred ways to implement the lean approach (Mudgal, 2020; Seth et al., 2017) VSM has also been widely used in industry for continuous improvement due to its ability to gather, analyse and present information in a very condensed manner (Marin-Garcia et al., 2021). With the help of modern tools, it has also been implemented in various domains (Balaji et al., 2020).

2.3 Quality filter mapping

QFM is a quality tool that has evolved from value stream mapping. It is similar to value stream mapping in that they both use symbols and icons from a common pool. However, a QFM differs vastly from a VSM in its use and information conveyed. A VSM is a production planning and management tool (Klochkov et al., 2019), whereas a quality filter map is a quality tool which is a part of the continuous improvement process (Saleeshya et al., 2012). QFM is a relatively new development in the field of quality management (Pud and Naik, 2012). QFM is used to graphically represent points on the production or assembly line which have scope for lapses in quality (Al-Zuheri et al., 2021). A QFM traces the defects due to which rejections take place, from the point of detection on the line, to the point of origin of the defect (Amran, 2020). This conveys information to the reader about the processes on the line which need attention so as to eliminate the traced defects, either by altering the process, or by introducing checks at the earliest point on the line for the defects, so that further value addition to a potential reject does not occur.

QFM is a technique which aims at a complete stabilisation (Haefner et al., 2014) of the production process, by means of integration of quality control into manufacturing flow. The advantage of QFM is to enhance stability and increase in productivity (Khalili, 2020; Lummus, 2006). Also, good components used, and time spent in assembly of a product that is found to be defective at the inspection point is saved, which can be utilised in a defect free assembly. The EOL inspection may be completely avoided.

The significance of the hidden factory is not clearly understood by the industry managers though they suffer the consequences of the unnecessary cost and time added. Eliminating the causes of defects through QFM prevents the flow of defects down the assembly line. We can quantify the savings due to the mapping of the causes of defects and hence demonstrate the importance of QFM to the industry. The present study brings out the concept of hidden factory and the application of QFM in a manufacturing industry.

3 Problem background – case study

QFM is a concept which can be easily understood theoretically. But how it can be implemented in an assembly line or manufacturing line can only be made clear with a practical implementation with the help of a case study (Yin, 1989). The company we have considered for our study currently manufactures three varieties of engines (350cc, 500cc, 535cc) at its manufacturing plant. They make use of assembly lines with components purchased by suppliers and/or developed in-house and assembled manually on a multiple station flow line. Finished products are then ready for 'firing' to verify performance and to determine failure of product. Firing and PDI is a cumbersome exercise which involves multiple inspections and dismantling of product based on sampling just before the batch is moved to the vehicle assembly line. This takes time and drains money and other resources. To reduce and eventually eliminate EOL inspection for engine assembly produced at the powertrain division of our case study company, the following reasons were found that were predominantly affecting the value of the product.

1 Value addition wastage: Every piece goes through a certain number of value addition processes. If at any station, or due to the fault of the supplier, a defect is generated in any component, it still goes through all the subsequent stations of the assembly. This defect is only checked for, detected and rejected (or reworked) at the EOL. This leads to precious value wastage on such defective pieces.

2 Time wastage: Defective components are assembled to completion. This leads to precious wastage of production time. If defects are detected at the originating station, then the component can be rejected or reworked immediately.

3 Sales quality: Defects with any piece, if detected by the customer, are sent back to the company service centre for repair or replacement. Such instances lead to customer dissatisfaction and loss of market share.

3.1 End-of-line rejections/rework

The inputs of this process include the control plan, process FMEA (failure mode and effect analysis), critical operations, EOL data, which are mapped together to indicate the root cause of failure and prevent them (Balaji et al., 2021). Suitable changes are recommended to critical processes in order to eliminate defects (Brad, 2008). If the process cannot be modified to ensure defect-free assembly, quality inspections are introduced after critical processes so that a defective piece does not move further in the line (Franceschini and Galetto, 2001). Remaining failure risks are controlled by statistical process control. This study involves development of QFM in the engine assembly line.

3.2 Methodology

At the company's powertrain division, the assembly line involved in the assembly of engine has a significant rate of rejection/rework at EOL inspection. The aim of this study is to identify these defects, their causes and use QFM approach to trace the defects to their sources and suggest to either rectify the defects at the originating point or reject the defective part if it cannot be rectified, thus allowing only defect-free sub-assemblies to move to the next station in the assembly line. QFM identifies the sources of defects, suggests means of detecting defects at source, and rectify or reject these defects at that point, saving operator effort, good parts and time, and consequently improving the productivity of good finished assemblies. The elimination of EOL inspection shall be treated as scope for improvement for the company's production plants.

4 Results and discussions

We want to analyse, monitor, improve, manage process performance for reducing undesired defects and wastages in order to engage in the pursuit of both product and service quality, for immediate benefits in the existing developmental cycle of a manufacturing plant. After identifying and resolving the defect, we can improve the quality of products that need attention by implementing appropriate measures, as it helps the plant to have improved processing capabilities and better decision-making strategies by collating data, deriving information from data, and learning from past mistakes during manufacturing/assembly line. Thus, by coming up with a simple mechanism for understanding and mitigating the defects endured in the line of production a manufacturing plant can become well adept in tackling any contingent situations. The following flow chart will give a better picture of the procedure carried out.

4.1 Step 1: identification of critical problems

A review and interpretation of assembly drawing is carried out to identify the critical operations in the assembly process. Critical operations are those which play an important role in ensuring the quality of product. Identification of critical operations forms the first step towards identifying processes for which process capability studies have to be done. The purpose of identifying these processes and doing process capability tests is to ensure that these critical processes do not contribute to defects. The assembly drawings were reviewed and the following critical operations were identified.

1 Sprag bolt tightening torque: A torque of 6.6±0.1 kg.F-m is applied to attach the sprocket with flywheel.

2 Clutch nut tightening torque: A torque of 4.8±0.1 kg.F-m is applied to attach the clutch plate with the main shaft.

3 Rotor nut tightening torque: A torque of 4.8 ± 0.1 kg.F-m is applied to attach the crankshaft assembly.

4 Magnetic bolt tightening torque: A torque of 2.0 ± 0.1 kg.F-m is applied

5 Inlet and exhaust cam spindle pressing load: A load of 1,269 kg and 1,451.50 kg is applied to press fit the cam spindle into the right hand crank case to attach the cam.

6 Spark plug right and left tightening torque: A torque of 1.4 ± 0.1 kg.F m and 2.5 ± 0.1 kg.F m is applied to tighten the spark plug with the cylinder head sub assembly.

7 Cylinder head tightening torque: A torque of 3.0 ± 0.1 kg.F m is applied to attach the cylinder head with the engine.

8 Stop plate tightening torque: A torque of 2.5 ± 0.1 kg.F m is applied to attach the stop plate with the right-hand crankcase.

9 Oil pump tightening torque: A torque of 0.5 ± 0.1 kg.F m is applied to attach the oil pump with the right-hand crankcase.

10 Hydraulic tappet screw tightening torque: A torque of 1.0 ± 0.1 kg.F m is applied to tighten the tappet to the right-hand crankcase.

4.2 Step 2: preparation of Pareto chart and identifying major defects

Pareto principle, also known as the 80–20 rule, is used widely to identify the ‘vital few’. It states that, for natural events, roughly 80% of the effects come from 20% of the causes. Figure 2 shows the pareto chart depicting the EOL rejections in the engine assembly line (Grosfeld-Nir et al, 2007; Arvanitoyannis and Savelides, 2007). The number of defects that occur along with their cumulative percentage are plotted. Nine major defects were identified in the engine assembly line, viz., cam noise, tappet noise, gear not engaged, misfiring, starting trouble, FD sprocket run out, auto DC noise, oil not flow, double gear noise. These represent 80% of the defects occurring in the line. Once these defects are identified, we need to identify the causes of these defects using cause-and-effect diagrams.

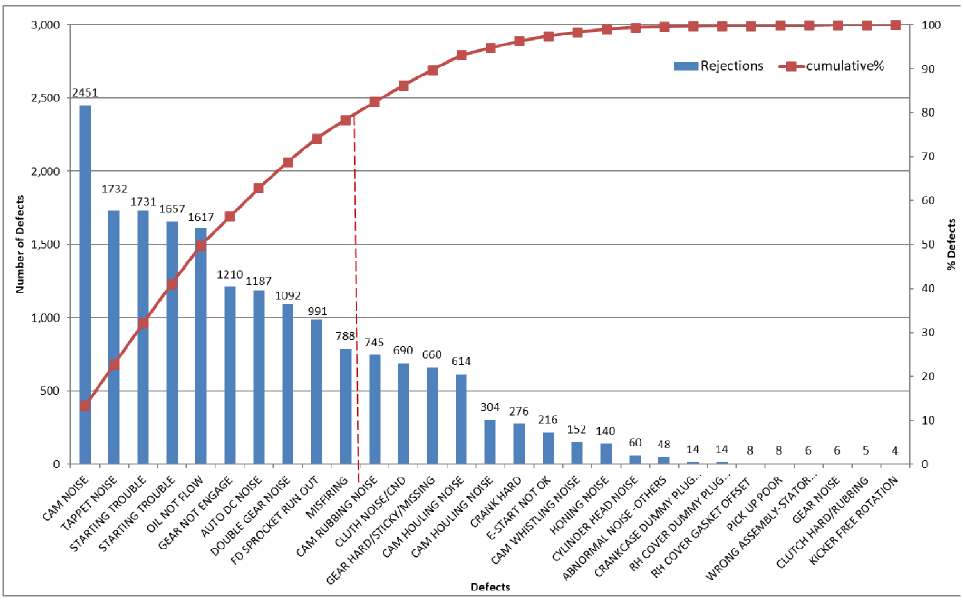
4.3 Step 3: cause-and-effect diagrams

Cause-and-effect diagrams (Ishikawa diagrams) are causal diagrams drawn to find the causes of the defects. Commonly used in quality assurance and prevention of defects, we are able to get a list of potential factors leading to the defect. Each cause or reason for imperfection will be a ‘source of variation’. These causes are categorised for identifying these sources of variation. They are typically categorised into five major branches (5Ms), viz., machine, method, material, man and measurement. Cause-and-effect diagrams can reveal key relationships among various variables, and the possible causes provide additional insight into process behaviour. Causes can be obtained from notes from historical data and through brainstorming. The root causes of these causes can be found with the help of 5-Why technique and these can be marked on the diagrams.

4.3.1 Cause-and-effect diagram for identifying causes

The cause-and-effect diagram is employed by the problem-solving team as a tool for collating all inputs systematically and graphically. A brainstorming session is conducted to ascertain the causes and root causes with a team of production managers, quality controllers and machinists. Without focusing on the history of the problem, the session works on why the problem occurred. It also displays a real-time 'snapshot' of the collective inputs of the team as it is updated. We discuss the causes of various defects in this section. The cause-and-effect diagram for 'cam noise' is illustrated in Figure 3. The causes of the other defects can be seen in Table 1. Similar diagrams can be drawn for each defect.

Figure 2 EOL rejections – Pareto chart (see online version for colours)



1 Cam noise: The root causes of Cam noise are mapped where variation in cam gear, cam spindle and cam sleeve present along with the incoming raw materials that arise due to rectification of quality issues at the supplier side create unwanted cam noise. Also sometimes lack of untrained professionals operating hydraulic machines might add up to the problem of cam noise. Most importantly, the method followed throughout the entire production line, especially, eccentric sleeve adjustments to compensate for the backlash contribute to cam noise.

2 Tappet noise: The root causes behind tappet noise are identified. The rocker bearing is tightened too much by the workers, due to improper tooling and lack of instructions. The supplied push rod is bent in many cases as it is not checked prior to assembly. In some cases, hydraulic oil filling is forgotten and is missing.

3 Starting trouble: The root causes behind starting trouble are mapped. Lack of training and awareness among manpower is one of the major human causes which arises mainly during the fitment of damaged coils and damaged wires. Improper cam

matching is one of the major contributors to this problem which occurs because of the operations performed by untrained professionals during the assembly phase. Damaged coils and problems with the relay continuity occurring in material handling also cause troubles in starting the engine. The only machine cause which leads to this problem arises due to improper wiring in the firing bed fixture.

4 Oil not flowing: The root causes leading to this problem are identified. Again, lack of awareness among workers leads up to some missing parts like the lee plug and oil hole in the crankcase. The same scenario is observed even when a machine plays the role of assembling a crankcase. During the assembly process, pump gaskets are not properly placed on the engine and at times, both sides of the crank have matching dimensions that lock the flow of air thereby affecting the flow of oil into the engine. Accumulated rust/dust, unexpected damages incurred/ burrs formations also tend to affect the free flow of oil into the engine.

5 Disengagement of gears: The root causes behind the disengagement of gears are mapped. This problem arises due to incorrect method used for aligning the gears namely, over-tightening the main shaft with the clutch, excessive torque produced at the upper and lower bearings, gear trains are not fixed/placed properly by men who don’t follow the instruction manual while assembling the gear. When it comes to the machining of gear shafts, if inadequate attention to detail is given and if cover diameter holes are not properly machined then the gear shaft fails to engage in working conditions.

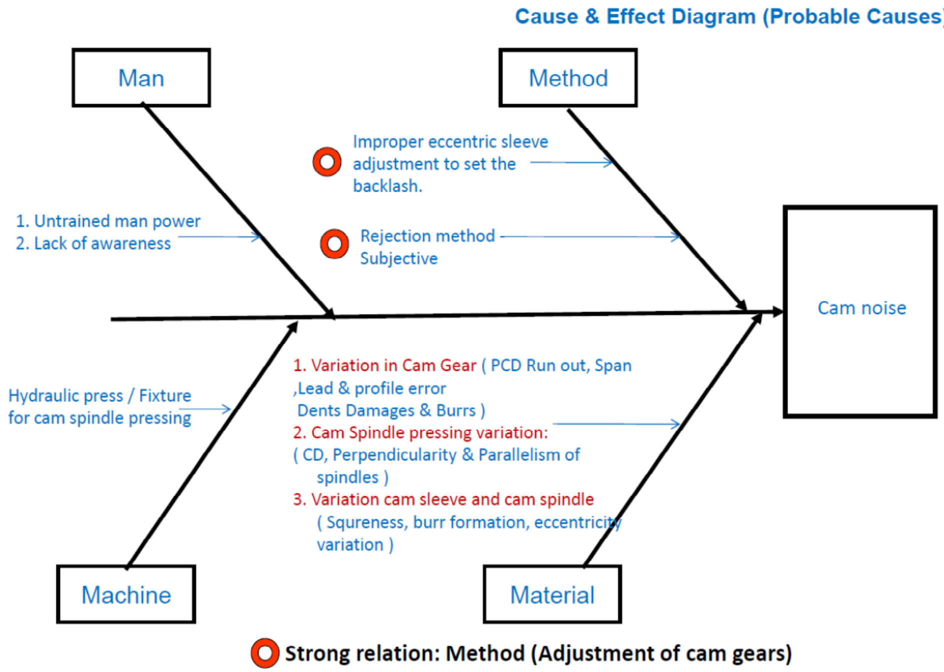
6 Auto DC noise: Root causes of auto DC noise are mapped. Only one machine cause is identified here, i.e., sources of errors that arise in RPM testing and gauge measuring instruments contribute to this cause. If the spring that goes into the flyweight is not properly fitted and if the flyweight supplied by manufacturers show some variation in their material composition (e.g., PCD run out, dents, damages, burrs, etc.), then experiencing auto DC noise is inevitable.

7 Double Gear Noise: The root causes behind the double gear noises are mapped. Lack of training and awareness among the manpower is one of the major human causes, while, following improper double gear adjustments could also add up to this problem of noise generation in double gears. Among the material causes, any possible variations in the shape of the double gears could also be a major contributor to this problem.

8 Runout of FD sprocket: The causes behind the runout of the FD Sprockets are mapped. Usage of a DC nut runner is one of the major machines causes that leads to this problem. A damaged oil seal and also lack of training among the manpower for fitting the distant piece and oil seal could also be among the contributors to this problem.

9 Misfiring: The root causes behind the misfiring in an IC engine are mapped. Problems with the carburetor and the variations in the spark plug could be the major material causes for this problem. Improper methods for fixing the flange-O-ring could also cause misfiring. Lack of awareness and training among the manpower in wiring could also contribute to this problem.

Figure 3 Cause-and-effect diagram – cam noise (see online version for colours)



4.4 *Step 4: preparation of QA mini matrix to determine defects and their originating stations*

The various entries of the QA mini-matrix are:

- Defect number: All the identified defects are numbered and it is entered in this column.
- Defect description: A brief description of the defect is given.
- Detection at the same station: If the defect is detected at the same station as its origination, it is given a green code. Else a red code is given
- Detection at a later station: If the defect is detected at a later station, a green code is given. Else a red code is given.
- Method: Method of detection like manual inspection, visual inspection, HV test bench, etc.
- Overall assessment: It gives the overall assessment of defect occurring detection. If the defect is detected, either in the originating station or at a later station and such a tool is prevented from pressing onto the customer a green code is used, else if there is a possibility of an engine with a particular defect passing on to the customer a red code is given. Subjective factors like noise, vibration is given yellow code.

Table 1 Quality assurance risk matrix

	Defects		*Causes*	*Same station*	*Next station*	*Method*	*Overall assessment*
1	Auto DC noise	A	Lift pin	Ws-35a		Dial gauge	100%
		B	RPM	Ws-35b		RPM test rig	<100%
		C	Cam reading				<100%
2	Oil not flow	A	Oil pump air lock	Ws-15			<100%
		B	Oil pump O-ring	Ws-15		Visual	<100%
		C	Oil pump gasket	Ws-15		Visual	<100%
		D	Rocker bearing	Ws-24			<100%
		E	Rh cc lee plug	Ws-08		Visual	<100%
		F	Rh cc dummy plug	Ws-08a	Leak test	Visual	100%
		G	Rh cc gpm missing	Final qc		Visual	<100%
3	Starting trouble	A	Rotor key missing	Ma-13		Sensor	100%
		B	Spark plug damage	Ws-36		Visual	<100%
		C	Carburetor flange	Ma-23		Visual	<100%
		D	Carburetor mixing	Ma-23		Visual	<100%
		E	Cam timing	Ma-10		Manual	<100%
		F	Head valve pressing	Ws-32b		Air leak test	100%
		G	Sprag clutch	Ws-36a		Manual	<100%
		H	Self-motor tight	Ma-09			<100%
		I	Piston rings	Ws		Visual	<100%
4	Double gear noise	A	Teeth problem	Ma-09		Visual	<100%
		B	Housing	Ma-09			<100%
5	FD sprocket runout	A	Oil seal pressing	Ws-13	Ws-14	Poke yoke	100%
		B	Sprocket damage	Ws-15		Visual	<100%
		C	Wrong fitment	Ws-15		Visual	<100%
		D	Tightening not done	Ws-15		Visual	<100%
		E	Over torque	Ws-15			<100%
6	Misfiring	A	Carburetor-dust, foreign materials	MA-23		Visual	<100%
		B	Spark plug damage	WS-36		Visual	<100%
		C	Carburetor flange	MA-23		Visual	<100%
			cam reading				<100%
		D	Lift pin	WS-35A		Dial Gauge	100%
		E	RPM	WS-35B		RPM test rig	<100%
		F	ROTOR key missing	MA-13		Sensor	100%
		G	CAM matching	MA-10		Visual	<100%
		H	Head valve pressing	WS-32B		Air leak test	100%

Table 1 Quality assurance risk matrix (continued)

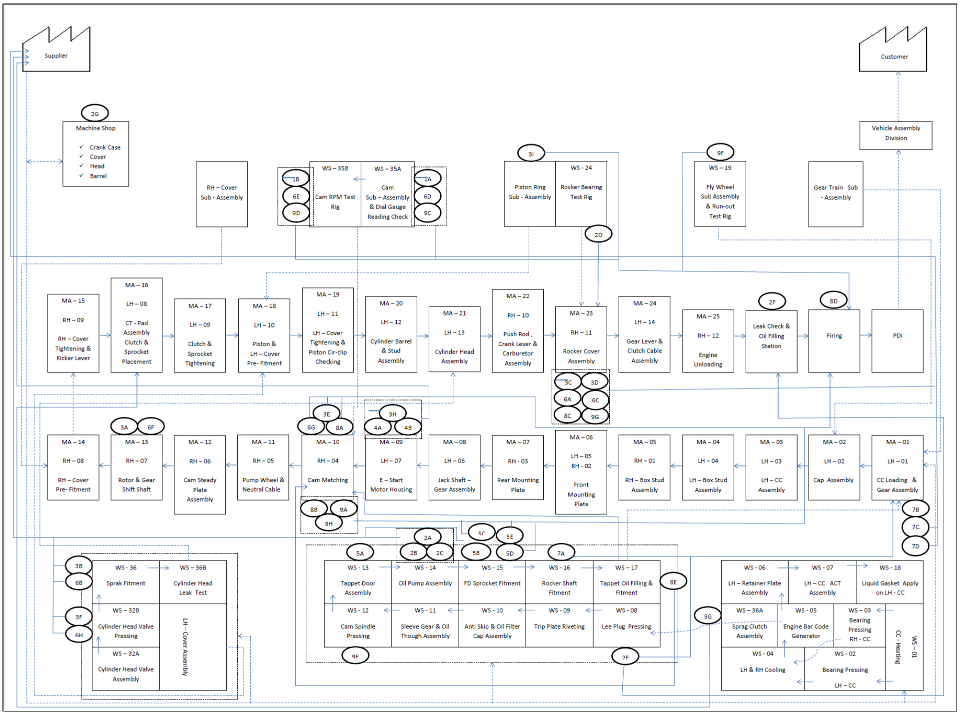
Defects			*Causes*	*Same station*	*Next station*	*Method*	*Overall assessment*
7	Gear not engage	A	Rocker shaft	WS-16	MA-01	Manual	100%
		B	Gear train teeth damage	MA-01		Manual	<100%
		C	Main shaft tight	MA-01	MA-03	Manual	100%
		D	FIRST gear miss	MA-01		Sensor	100%
8	Tappet noise	A	CAM over slag	MA-10		Manual	<100%
		B	CAM sleeve nut loose	MA-10		Manual	<100%
		C	Push rod bend	MA-23		Visual	<100%
		D	Rocker bearing over tight	Firing			<100%
		E	Hydraulic tappet oil filling miss	WS-17	MA-10	Visual	100%
9	Cam noise	A	CAM over slag	MA-10		Manual	<100%
		B	CAM sleeve free rotation	MA-10		Manual	100%
		C	Lift pin	WS-35A		Dial Gauge	100%
		D	RPM	WS-35B		RPM test rig	<100%
		E	CAM spindle pressing	WS-12	MA-10	Visual	100%
		F	Fly Wheel runout	WS-19			<100%
		G	Push rod bend	MA-23		Visual	<100%
		H	CAM sleeve nut loose	MA-10		Visual	<100%
		I	Cam reading				<100%

Various defects and their causes along with their stage of occurrence are provided in the matrix given in Table 1. For instance, the defect of Auto DC noise occurs mainly due to two reasons such as cam reading lift pinned and the RPM of the motor and both of these are identified to be occurring in workstations indexed 35-A and 35-B respectively. While the former can be identified by using a dial gauge at the same workstation and can be prevented from passing on to the customer it is shaded, while the latter which can be identified by using an RPM test Rig setup has the possibility of it being passed on to further stages, it is not shaded. The overall assessment given as 100% or <100%, indicates whether the cause of the defect can be definitely identified or not. The method through which it can be identified, viz., visual, manual or with particular equipment or sensors is also given along with the station in which it can be identified. This gives a clear picture of whether or not the causes of the defect can be detected without passing them on to the customers. In a similar fashion various defects along with their respective causes are mapped in the given matrix.

4.5 Step 5: prepare quality filter map and implement measures for identified problem causes

Figure 4 shows the quality filter map for the engine assembly line. We can see the complete process flow of the assembly line along with the various machines used for processing. The serial number of the causes from the QA mini-matrix are taken and represented as bubbles in the machine in which the causes originate. With the main aim of eliminating the end of line rejections the process of QFM is done with various causes mapped at the workstations in which they occur and thereby helping in identifying the areas in which they occur.

Figure 4 Quality filter map – engine assembly line (see online version for colours)



The interpretation of the quality filter map was explained with an example as follows. For example, in the RPM test rig (WS-35B), located in the first row of machines, three causes are mapped as can be seen from Figure 4. The three causes are 1B, 6E and 9D. The respective defects are auto DC noise, cam noise and misfiring. If we can ensure that the correct RPM is maintained in the RPM test rig, these three causes will be eliminated leading to a reduction in the occurrence of these defects. Once the causes are mapped, it offers a visual tool through which we can take corrective action and thus mitigate defects.

Figure 4 is a typical representation of the quality filter map for a particular assembly line. The same step-by-step methodology can be used in any manufacturing or assembly line with a hidden factory. There are several ways of defect reduction expounded in literature as well as in practice. Several tools like root cause analysis (Gangidi, 2019), FMEA, lean manufacturing and six-sigma techniques (Vinodh, 2020) are used to mitigate risks, whereas QFM provides a tool to prevent these defects from occurring. It also helps to identify the causes of these defects and is a proactive approach to build preventive methods. To avoid the reduction in profits or passing on the cost to the customer, we can use this map to identify critical causes. Also, we can use process FMEA to take specific actions to eliminate or mitigate these causes. A mitigation of the defects can also be done by studying each defect and use modified assembly techniques or manufacturing methods to overcome them.

5 Conclusions

Defects are considered worrying, but unavoidable by many companies. They are a drain on the profits and are an embarrassment to the company; hence the hidden factory. To address these defects, many companies adopt reactive measures such as 100% inspection and rework, which are costly as well as time-consuming. QFM offers a unique perspective to defect reduction. Instead of reactive measures to the defects caused, the major defects are identified, and their causes found out through a systematic analysis. The defects are traced from the point of detection to the point of origin and these causes are mapped on to the process flow of the product. Awareness of these causes and avoiding their occurrence reduces the need to introduce inspection at multiple points as well as at the end of the line. The illustration shown through the case study will be an eye-opener and useful for reducing the quality defects. The methodology of QFM further pushes the companies to evaluate and eliminate these defects through root cause analysis and take suitable measures to avoid them. QFM should be a periodic process in any manufacturing or assembly line so as to produce defect-free products and enhance profitability.

6 Limitation of study and scope for future work

In the present study, the focus is limited to the engine assembly line. In future, this methodology can be expanded to include the other assembly as well as manufacturing lines. Also, the parts received from suppliers should be checked and similar implementation done to minimise incoming defects. Hence, the study should include supply chain also to ensure better quality and timely delivery. Identifying the rejections is done manually through testing equipment and visually only. One of the improvements that can be made is to automate this identification process using sensors and IoT. Such techniques as IoT to monitor the components and assess them at receipt. Similar to QFM, the supply chain risks can be mapped to the processes in the supply. We can thus enhance process efficiency and ensure timely delivery to the customer.

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