MANTECH Publications

Journal of Advance Manufacturing System and Technology
Volume 7, Issue 2, July – December, 2022

Automotive Industry Control Processes in Manufacturing

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Abstract

Control of the manufacturing processes is a highly significant function in all firms. Because this should be created by a multidisciplinary team, it will have an impact on the whole product production process. As a result, it is critical that its deployment be planned in order for it to be effective. The majority of potential problems may be avoided and manufacturing processes improved if the correct approach is employed at the right time. The goal of this article is to propose a framework for correctly controlling processes in the automobile industry by utilizing the right technique, FMEA, to detect gaps in the early stages of product and process development and prevent these gaps from occurring during regular production.

Keywords: *DFMEA, PFD, PFMEA, Control Plan, FTQ*

INTRODUCTION

Controlling manufacturing processes is a critical task for all types of industrial businesses. This activity, which should be designed by a multidisciplinary team, will have an impact on the whole product production process. As a result, it is critical to properly plan its execution in order for it to be effective. This prior preparation prior to the deployment of the process control may take some time and will necessitate agreement between the participants and their supervisors; otherwise, its efficacy may be jeopardized. The type of strategy used may alter based on the size and organization of the firm; nevertheless, the methodological principles remain the same. Most organizations utilize a variety of different production techniques to create a variety

of different goods. These processes are meant to meet the demands and requirements of the consumer, so businesses should make every effort to optimize them as much as possible in order to surpass the client's expectations. If the correct approach is utilized at the appropriate moment, it will be feasible to prevent the majority of the potential problems and increase the performance of the manufacturing processes.

As the major purpose of the companies is to gain profit in order to survive and expand, it is vital to provide a method to enhance and manage the manufacturing processes in order to aid firms in becoming more lucrative. In this context, there is a collection of tools that may be used to regulate processes and create a set of corrective and preventative actions when used appropriately. These tools are not new and have been used successfully in the past.

One of these tools is the Failure Mode and Effects Analysis (FMEA). The FMEA is widely regarded as one of the most effective engineering methods for design and process evaluation (ex. Franceschini & Galetto, 2001; Carbone & Tippett, 2004). The major purpose of this article is to build a framework to correctly regulate the processes in the automobile sector, using the right technique—FMEA—to detect the gaps in an early phase of the product and process development, and avoid these gaps from emerging during regular production. The following is how this paper is organized:

A literature overview of Failure Mode and Effects Analysis (FMEA), Design FMEA, Process Flow Diagram (PFD), Process Failure Mode and Effects Analysis (PFMEA), Risk Evaluation Techniques, and Control Plans follows the introduction. Following that, a proposed framework is provided to make the management of the production of the product and process development, as well as its control, more efficient. Finally, some conclusions are formed.

Failure Mode and Effects Analysis (FMEA)

The FMEA is a decision-making technique used to prioritize remedial actions in order to improve product/system performance by eliminating or lowering failure rates (Price et al., 1992). There is no rule of thumb for the number of stages required to execute an FMEA; the number of steps depends on the amount of detail evaluated by the researcher. Pillay and Wang (2003), for example, propose twelve phases.

However, McDermott el al. (2009) argues that the implementation of a FMEA should follow the following top ten steps:

1. Examine the procedure or product.
2. Consider probable failure modes.
3. List the possible failure modes.
4. Assign a severity ranking for each impact.
5. For each failure mode, assign an occurrence ranking.
6. Each failure mode and/or effect should be assigned a detection ranking.
7. For each effect, compute the risk priority number.
8. Determine the failure modes' priority for action.
9. Take the necessary steps to remove or decrease the high failure modes.
10. As the failure modes are decreased or removed, compute the resultant priority number (RPN).

The RPN was described here since it is the most often used strategy for identifying priorities and developing actions for improvement. It is calculated by multiplying the severity, incidence, and detection ratings by the score. The RPN denotes the combined impacts of S (severity), O (occurrence), and D (detection). The RPN is determined by multiplying these three ratings together: RPN = SxOxD. The greater the RPN, the greater the likelihood that the mode would fail, necessitating a higher priority for remedial action (Vinodh & Santhosh, 2012). The severity value is associated with the most severe effect for a certain failure mode. (Bester Feld et al., 2004). The chance that a given cause/mechanism may occur, resulting in the failure mode, occurs during the design life. The detection rank corresponds to the best detection control mentioned in the current design control detection column (Besterfield et al., 2004).

The classic FMEA employs five scales with scores ranging from 1 to 10 to assess the likelihood of occurrence, severity, and detection (Pillay & Wang, 2003). This five-point Likert scale (1–5) helps team members participating in the analysis reach an agreement (Welborn, 2007). It should be noted that, while the RPN is the most commonly used model technique for identifying priorities and developing actions for improvement, some literature has significant critiques, specifically about the calculation formula and how it prioritizes risk-reduction strategies (ex. Pillay & Wang, 2003; Puente et al., 2002, Sankar & Prabhu, 2001; Chang et al., 2001). Aside from that, the RPN approach is used in the context of this inquiry.

1955	Potential Problems Analysis (PPA) Kepner-Tregoe
1963	Development and application of FMEA by NASA (Apollo Project)
1965	FMEA–Application in more techniques of Aviation & Space
1975	Use in nuclear techniques
1977	Implementation in Automotive Industry (SAE–Congress by Ford)
19980	More applications in Europe, USA and Japan

In terms of the scope of FMEA use, Stamatis (2003) provides examples from several sectors. For the first time, the FMEA approach was created and applied in the United States Army. The American army started employing FMEA in the 1970s and published the army standard, "MIL-STD-1629: Methods for Undertaking a Failure Mode Effects and Criticality Analysis," in 1974. There was also a second version of MIL-STD-1629A in 1980. (1980). In the 1970s, its application range was extended firstly to the aerospace and automotive sectors, then to general manufacturing (Table 1 shows the FMEA History).

In the ISO 9000 series, the International Organization for Standardization (ISO) suggested the FMEA in 1990. (Teoh & Case, 2005; Chang & Wen, 2010). FMEA is now mostly used in the industrial manufacturing of equipment, automobiles, mechanical, and electronic components. FMEA is an integral tool in all of this, both for the engineering systems for automobile production, as well as for their suppliers.

In general, its purpose is to prevent failures in a product, part, or process by enabling early intervention at the source of the failure or defect to avoid it. It indicates that the primary goal is to eradicate the failure's core causes so that they do not occur again and that there is no need to control them in the final product. If this will not be achievable for everybody, these failures should be limited and regulated. Because the drawings, tools, or components are still under development, the expenses associated with the removal of failures might be lowered if the manufacturing process control is introduced earlier in the first phase of product development.

Design FMEA

Design Failure Mode and Effects Analysis (DFMEA) is a major and a commonly used risk assessment and effects method to

identify the probable failure modes throughout the product development (AIAG, 2008b; Zheng et al., 2009). The DFMEA is concerned with the design of the final product that will be given to the client (end user).

Before beginning mass manufacturing of a product or process, risk assessment is crucial to determining its flaws. As a result, this analysis improves work quality and dependability, and it is a critical aspect in increasing competitiveness. This sort of analysis, when performed early in the product development process, can help to reduce the likelihood of significant failures and their repercussions.

The Failure Mode and Effects Analysis (DFMEA) approach is used specifically to product design in DFMEA. The primary purpose of DFMEA is to enhance a design's resilience by methodically cataloguing its probable failure modes. It is used to guarantee that all design failure modes have been examined and analysed in order to reduce and, in some cases, eliminate them (Chang & Wen, 2010). In this regard, the multidisciplinary team should study the design during DFMEA analysis to identify design functions, assess the implications of every probable failure, and find plausible reasons of each failure. All of the most essential product attributes are recognised based on the design and client needs analysis. The characteristics that have a significant influence on manufacturing should be included in the FMEA analysis process.

The FMEA procedure allows for the identification of design flaws prior to release and improves the capacity to discover failure modes and/or causes during design development and validation. The DFMEA material should be consistent, utilise appropriate vocabulary, and avoid speculative phrases. As seen in the following example, the DFMEA should be straightforward and objective (Table 2).

Failures Modes	Avoid:	Cracks	Say:	Housing cracks
Effects	Avoid:	Loss of Control	Say:	Unable to give energy to one Wheel at low speed
Causes	Avoid:	Incorrect design	Say:	Fatigue, design insufficient for vehicle loads
Design Controls	Avoid:	Design validation	Say:	Material analysis, fatigue test, in-vehicle durability

As explained above, the DFMEA is an important tool for risk management during the design phase of the product development. In this tool four elements of design risk are evaluated (Vinodh & Santhosh, 2012):

Severity (S) - is the value associated with the most serious effect for a given failure mode. The severity for different failure modes is rated between 1 and 10;

Occurrence (O) - is the likelihood that a specific cause of failure will occur;

Detection (D) - is the rank associated with the best detection control listed in the current design control detection column;

Risk Priority Number (an overall assessment of the risk of a potential design problem) which result from the expression SxOxD.

DFMEA can be deployed in engineering design with different levels of complexity and in different situations and with different scopes, such as (AIAG, 2008b):

1. A new design or new technology; the FMEA scope is the entire design to be analyzed.
2. Modify an existing design and FMEA; the scopes are the modifications, the interactions with the unchanged portions of the design, and the field history.
3. Use an existing design and FMEA for a different application or environment; The FMEA scope is the application interfaces of the environment factors and the field history. This tool makes possible to anticipate the main problems, in order that whenever possible preventive actions can be taken. It also allows identifying which activities or controls should be used to assure that the product is well designed, through the zero non conformities detection.

Process Flow Diagram

The level of detail in a Process Flow Diagram (PFD) might be different depending on the process development phase (prototypes, pre-serial or serial production) (AIAG, 2008a).

The PFD should be done by a multidisciplinary team from the different areas of the organization, such as engineering, quality, manufacturing, logistics, etc., in order to have all specific knowledge and feedback. The PFD is the first document to be created in terms of the manufacturing processes identification. Here all the manufacturing processes

associated to the production of a specific product must be identified in the correct sequence, starting with the raw material receiving until the final product expedition. Also the product and process characteristics to be controlled and the type of operation (fabrication, movement, storage and inspection) should be identified (ISO 10628: 1997).To create such a document, the team should consider all the enterprise and customers requirements, the system design, equipments involved in the different processes and also all lessons learned from similar products (McDermott, 2009).

PFD should be sequentially numbered by a step number, which will indicate the position of the process in the sequence which will establish the link between PFD, Process FMEA and Control Plans (AIAG, 2008a). Whenever a process change occurs the PFD should be analyzed and reviewed.

Process FMEA

As mentioned, the DFMEA corresponds to a risk assessment tool to minimize the potential critical failures and their consequences, in an early stage of the product development however, this by itself is not enough. It is recommended that all planning should be done in a structured way.

The Process Failure Mode and Effects Analysis (PFMEA) intends to capture the potential failures and their effects on process. The PFMEA technique was first reported in the 1920s but its use has only been significantly documented since the early 1960s (Bell et al., 1994). Such as DFMEA, PFMEA was developed in the USA in the 1960s by the National Aeronautics Space Agency (NASA) as a means of improving the reliability of military equipment (MIL-STD- 1629A: 1980). Since then, it has been used in the automotive industry in the early 1970s, and its use has been accelerated in the 1990s to address the major quality and reliability challenges caused by the Far Eastern car manufacturers. In addition, the changes in the beginning of this century in the law on corporate responsibility have led to companies reviewing their product design safety through the use of the PFMEA methodology (Johnson & Khan, 2003).

In general terms, the main reason for undertaking a PFMEA is to continually improve the reliability of products and processes to reduce warranty and increasing customer satisfaction (Aldridge & Taylor, 1990). PFMEA along with other quality tools support the practice and philosophy of problem prevention and

continuous improvement, which are key elements of Total Quality Management (TQM) (Johnson & Khan, 2003).

Of course the goal is also to identify actions that could eliminate or reduce the probability of the occurrence of failures. There are two types of actions to be taken: Preventive and Detection actions. The first ones are measures which minimize the occurrence of potential failure causes during the process (VDA, 1996). The Detection actions are the measures put in place to detect the failure and/or the cause.Also in PFMEA the same four elements of the DFMEA are evaluated:1) severity,; 2) occurrence; 3) detection; and 4) Risk Priority Number(RPN).

Note that a reduction in severity ranking can only be achieved through a design change to the system or sub- system that uses the device (Le Saux, 2006).

The team that should create and analyse the PFMEA should be the same team who have documented the related PFD. The processes that will be analyzed by the multidisciplinary team are the ones identified on the PFD, and the different step numbers will also appear in the same way in PFMEA to establish the link.

Some of the main inputs needed to create a PFMEA are the following:1) The Process Flow Diagram (PFD) with all operations or elementary processes identified in sequence by the step number.2) DFMEA where characteristics to be followed by the manufacturing site are identified.
Lessons learned from similar products;
Customer specifications;
Manufacturing process specifications.

All these inputs are needed in order that the team will have all the necessary knowledge about the product and the related processes to manufacture it.

Risk Evaluation Methods

The most common methods to identify and prioritize the risks in order that actions can be taken are the Risk Priority Numbers (RPN) and Criticality analysis. The RPN analysis should be performed based on the Pareto law and created based on the different RPN‟s of the FMEA. To develop that, the team must rate the severity of each effect of failure, rate the likelihood of occurrence for each cause of failure, rate the likelihood of prior detection for each cause of failure and finally calculate the RPN by obtaining the product of the three ratings: RPN = Severity x Occurrence x Detection [Weibull.com, 2008].

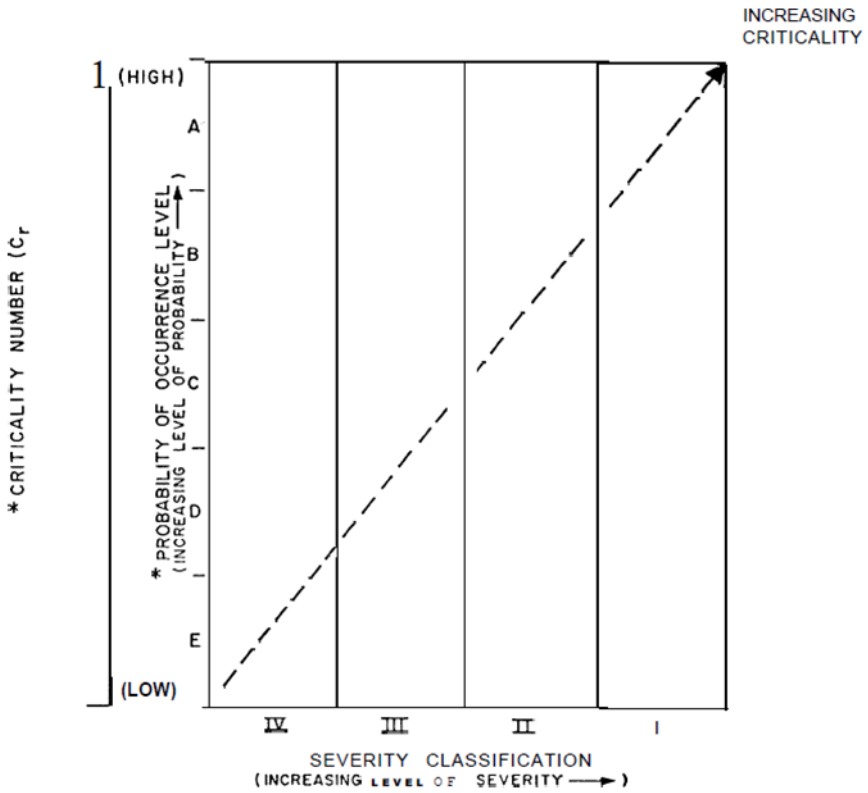

Figure 1. Example of criticality matrix (MIL-STD-1629A:1980)

Then the RPN can be used to prioritize problems for corrective actions implementation and also to compare issues [Weibull.com, 2008]. The Criticality analysis is a method where each potential failure mode is ranked according to the combined influence of severity and probability of occurrence as it is mentioned on figure 1 (MIL-STD-1629A:1980).

To use this method the team must rate the severity of the potential effects of failure, rate the likelihood of occurrence for each potential failure mode and compare the failure modes via a Criticality Matrix, which identifies severity on the horizontal axis and occurrence on the vertical axis. PFMEA is a in-progress document and due to that it should be changed whenever it is needed with the purpose of being a constant picture of the real manufacturing process (Crow, 2002). As soon as the revision and analysis for a certain product and/or process is done the problems can be sooner anticipated, solved and monitored avoiding by this way the deployment of more expensive corrective practices in the forward phases.

This technique has obviously limitations, caused by issues such as the understanding

of cause and effect and the practical aspects of managing the data and keeping it up to date. But, if taken into account some recommendations is a useful technique. For example, in a study performed by Johnson & Khan (2003) Team‟ and „Teamwork‟ are the most important topic in terms of the successful implementation of a PFMEAs, followed by „Technical‟.„Technical‟ issues created the greatest number of concerns, with the fundamental understanding of the practical aspects.

Control Plans

A Control Plan (CP) is a description of methods used to control the product and the processes in order to minimize their variation (Le Saux, 2006). It describes the manufacturing process associated to the product and process characteristics, the method to measure and control these characteristics, the sample size to be checked, the frequency of the inspection and the reaction plan, in case that these characteristics are out of control.

It is recommended that the team who created the previous documents (PFD and PFMEA) will be the same that create the control plans for the related product and processes (Le Saux, 2006; AIAG, 2008a). Also Control Plans should be linked to PFMEA and PFD through the process step number.

The following information should be used during the development of the CP:

- CP from previous production phases and / or similar products.
- PFD from previous production phases and / or similar products.
- DFMEA, PFMEA.
- Operator work instructions. These documents should consider all special characteristics and control methods identified in CP.
- Lessons learned from similar products / processes.
- Team knowledge concerning the product / process.
- Information related to the design review.
- Information related to the processes capability.
- Quality performance (FTQ, customers complaints, product audits, etc

The CP should be an in-progress document, presenting at all the time the actual control methods and these ones should be continually evaluated in order to have a better effectiveness of the process.\

Proposed Framework

It is evident that an appropriate management of the manufacturing process and process development, as well as its control, provides a more effective plan, contributing to improved awareness and better results.

To make that all this process became more efficient in terms of timing, we should think about the usage of software; on the one hand, it will minimize the engineers' work during these documents' conception, and on the other, it will enable that, for a certain elementary process, the complete know-how, customer complaints, problems, and developed actions in different products are consolidated in the related PFMEA and CP.

For that, for each elementary process identified, a PFMEA Template should be created containing all this information in order to generate a CP for this process (figure 2). As the way to control the different processes is basically the same for the different products, for each PFMEA template there will be a CP template.

Figure 2. Templates development

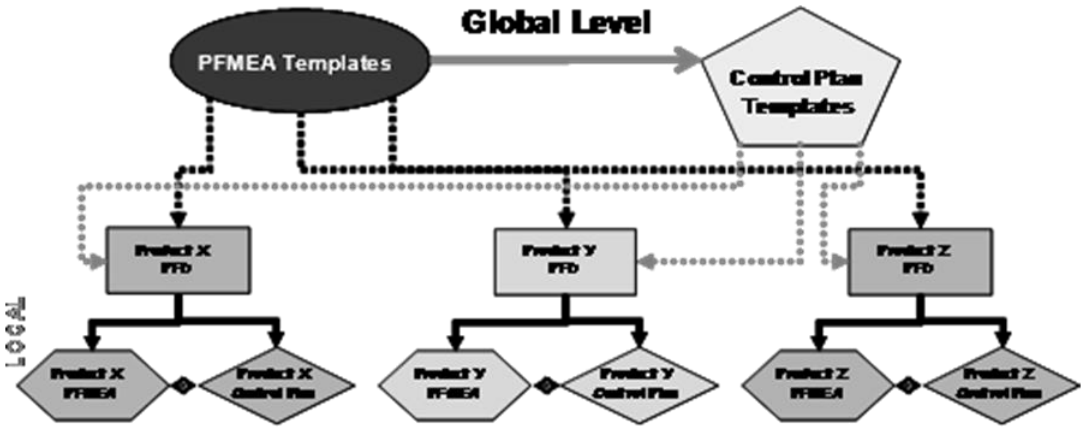

Figure 3. Conception of documents per product

These templates should be the working basis for the team that is starting on a new PFMEA (also considering all the inputs mentioned on item 4).

So, in the manufacturing plants, during the creation of a PFD for a product, through the selection of all elementary processes previously created (Templates), all the information related to PFMEA and CP will come together automatically. During the creation of a PFD the correspondent PFMEA and related Control Plans are also created automatically, as can be seen in figure 3.

CONCLUSIONS

To get a better-designed product, a DFMEA should be performed, attending to all the characteristics associated with the manufacturing process. If the DFMEA is done during the design phase, corrections can be made to address the identified gaps, avoiding more costs in manufacturing. Then, all the elementary processes needed to produce one complete product should be identified, and the PFD should be created.

After the PFD is complete (processes in sequence and characteristics identified), the PFMEA analysis should be started; here all potential failures and causes should be identified, and actions should be developed to prevent them as much as possible. For the remaining ones, detection controls should be identified.

After this analysis, the correspondent control plans for each elementary process should be created, and all the controls defined on the PFMEA to control the product and the process should be considered for the different failures of each process.

These documents (PFD, PFMEA, and Control Plans) are linked through the step numbers and created in the order (see Figure 4).

So, if all risks related to the product are identified in the DFMEA, manufacturing can take them into consideration during the PFMEA analysis and method definition, as some of the characteristics might impact the process. Also, the PFD sequence might have to be adjusted, due to some characteristics that came from DFMEA. Based on all this analysis, control plans make it possible to identify which items need to be controlled, how, and by whom. If all this analysis is done at the proper time of the project's development or conception, lots of problems in production can be avoided, and consequently, costs will be reduced.

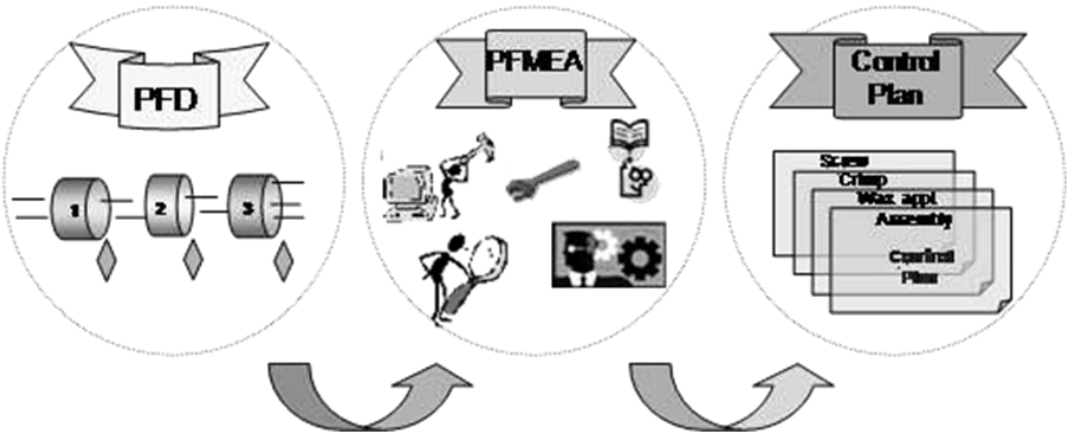

Figure 4. Connection between the manufacturing processes control documents.

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