Manufacturing Proceses control in Auto motive Industry

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Abstract: *The manufacturing processes control is a very important activity in all companies. As this should be developed by a multidisciplinary team, it will affect all the product manufacturing process. So, it is very important that its implementation will be planned in order to be effective. If the correct methodology is used on the right time, it will be possible to prevent the majority of the potential problems and improve the manufacturing processes. The purpose of this article is to suggest a framework to control properly the processes in the automotive industry, using the right approach – FMEA- to identify the gaps in a early phase of the product and process development, and prevent these gaps to occurr during normal production.*

Keywords: PFD–Process Flow Diagram; DFMEA – Design Failure Mode and Effects Analysis; PFMEA – Process Failure Mode and Effects Analysis; Control Plan; FTQ – First Time Quality.

1. Introduction

The control of the manufacturing processes is a very important activity for all kind of industrial companies. As this activity should be developed by a multidisciplinary team, it will affect all the product manufacturing process. So, it is very important to plane carefully its implementation in order to be effective. This previous preparation before the implementation of the processes control might take some time requiring an agreement between the participants and their supervisors, otherwise its effectiveness might be compromised. The type of the deployed approach can be different depending on the size and organization of the company; however the principles in terms of the methodology are the same.

Most of the times the companies use a lot of different manufacturing processes to produce a lot of different products. These processes are designed to satisfy the customer needs and requirements and due to that, the companies should develop efforts to optimize them as much as possible, in order to exceed the customer expectations. If the correct methodology is used on the right time, it will be possible to prevent the majority of the potential problems and improve the performance of the manufacturing processes.

As the main objective of the companies is to get profit in order to survive and growth, it is critical to suggest an approach to improve and control the manufacturing processes in order to help companies in becoming more profitable. in this context, there is a set of tools, that allow to control the processes which correctly applied will generate a set of corrective and preventive actions. These tools are not new and have been used with good practical results. One of these tools is the Failure Mode and Effects Analysis (FMEA). The FMEA has been considered one of the most efficient engineering tools for design and process evaluation (ex. Franceschini & Galetto, 2001; Carbone & Tippett, 2004).

The main objective of this paper is to a framework to control properly the processes in the automotive industry, using the right approach – FMEA- to identify the gaps in a early phase of the product and process development, and prevent these gaps to occurr during normal production.

This paper is structured as follows. After the introduction a literature review on the Failure Mode and Effects Analysis (FMEA), Design FMEA, Process Flow Diagram (PFD), Process Failure Mode and Effects Analysis (PFMEA), Risk Evaluation methods and Control Plans is present. After that a recommended framework is suggested to became more efficient the management of the manufacturing of the product and processes development, as well as its control. Finally some conclusions are drawn.

2 - Failure Mode and Effects Analysis (FMEA)

The FMEA is a decision-making tool for prioritizing corrective action to enhance product/system performance by eliminating or reducing failure rate (Price et al., 1992). Concerning the steps to implement an FMEA, there is not a rule of thumb, the number of steps depend on the level of detail considered by the researcher. For example, Pillay & Wang (2003) present twelve steps. However McDermott el al. (2009) argue that the implementation of a FMEA should follows the following top ten steps:

1) Review the process or product.
2) Brainstorm potential failure modes.
3) List potential failure modes.
4) Assign a severity ranking for each effect.
5) Assign an occurrence ranking for each failure mode
6) Assign a detection ranking for each failure mode and/or effect.
7) Calculate de risk priority number for each effect.
8) Prioritize the failure modes for action.
9) Take action to eliminate or reduce the high failure modes.

Calculate the resulting priority number (RPN) as the failure modes are reduced or eliminated. Here, the RPN was presented since it is the most common method to identify the priorities to develop actions for improvement. It is obtained by multiplying the score provided by the ratings of

severity, occurrence and detection. The RPN represents the multi-effects of S (severity), O (occurrence) and D (detection). The RPN is calculated by multiplying together these three ratings: RPN=SxOxD.
Higher the RPN, higher the chance that the mode will fail and subsequently demands higher priority for corrective action (Vinodh & Santhosh, 2012). Severity is the value associated with the most serious effect for a given failure mode. (Besterfield et al., 2004). Occurrence is the likelihood that a specific cause/mechanism will occur resulting in the failure mode within the design life. Detection is the rank associated with the best detection control listed in the current design control detection column (Besterfield et al., 2004).

The traditional FMEA uses five scales and scores from 1 to10, to measure the probability of occurrence, severity and the probability of detection (Pillay & Wang, 2003). This five-point likert scale 1-5 scale facilitates consensus among team members involved in the analysis (Welborn, 2007). Note that despite the RPN is the most used model method to identify the priorities and to develop actions for improvement, some literature presents some criticisms, particularly regarding the calculation formula and how it prioritizes measures to reduce the risk (ex. Pillay & Wang, 2003; Puente et al., 2002, Sankar & Prabhu, 2001; Chang et al., 2001). Besides this, in the context of this investigation the RPN method is followed.

Regarding the scope of the FMEA application, Stamatis (2003) presents examples of application in different kind of industries. The FMEA methodology was developed and implemented for the first time in the United States Army. The American army began using FMEA in the 1970s and in 1974 produced the army standard, ‘‘MIL-STD-1629: procedures for performing a failure mode effects and criticality analysis”. In 1980, there was also a second version of MIL-STD-1629A (1980). In the 1970s, its application field was extended firstly to the aerospace and automotive industry, then to general manufacturing (Table 1 shows the FMEA History).

“as indicated in Table 1 (Appendix)”

In 1990, the International Organization for Standardization (ISO) recommended the FMEA for design review in the ISO 9000 series (Teoh & Case, 2005; Chang & Wen, 2010). Nowadays, FMEA is mainly deployed in the industrial production of machinery, motor cars, mechanical and electronic components. In this context, FMEA is an integrated tool in all engineering systems for automotive manufacturing, as well as for their suppliers.

In general, its goal is to prevent failures that might occur in a product, part or process, enabling act early in the cause of failure or defect as a way of avoid it . It means that the main objective is to eliminate the failures root causes, in order that they cannot happen again, and there will be no need to control them in the final product. If this will not be possible for all, these failures should be reduced and controlled.

If the preparation of the manufacturing processes control is deployed sooner in the initial phase of the product development, the costs associated to the elimination of the failures could be reduced since the drawings, tools or parts still under development.

3. Design FMEA

Design Failure Mode and Effects Analysis (DFMEA) is a primary and a widely used risk assessment and impacts tool to identify the potential failure modes during the product development (AIAG, 2008b; Zheng et al., 2009). The DFMEA focuses on the design of the product that will be delivered to the final customer (end user).

Risk assessment is a critical to determine the weaknesses of a product or process, before starting its mass production. Consequently, this analysis provides a better quality of work, as well as greater reliability and is a key factor for the improvement of competitiveness.

This type of analysis, in an early stage of a product development, can contribute to minimize the potential critical failures and their consequences, rather than in a more advanced stage.

DFMEA is the application of the Failure Mode and Effects Analysis (FMEA) method specifically to the product design. The main DFMEA’s goal is to increase the robustness of a design by systematically listing its potential failure modes. It is used to ensure that all design failure modes have been considered and assessed in order to their reduction and even elimination (Chang & Wen, 2010). In this sense, during DFMEA analysis, the multidisciplinary team should analyze the design to identify the design functions and to assess the effects of any potential failure, and determine possible causes of each failure. Based on the design and customers requirements analysis all the most important characteristics of the products are identified. The characteristics with important impact also on manufacturing should be considered in the Process of FMEA analysis.

The FMEA process makes possible to expose weaknesses in the design before release and improve the ability to detect failure modes and/or causes during design development and validation.

The DFMEA content should use the right terminology, be consistent and avoid speculative terms. The DFMEA should be clear and objective as can be seen in the following example (Table 2).

“as indicated in Table 2 (Appendix)”

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. *T*he 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 analysed.

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.

4. 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..

5. 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.

3) Lessons learned from similar products;

4) Customer specifications;

5) 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.

5.1. 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].

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).

"as indicated in Figure 1 (Appendix)"

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.

6. 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.\

7. Proposed Framework

It is evident that an appropriate management of the manufacturing f the product and processes development, as well as its control, provides a more effective plan, contributing to improve the awareness of attitudes and for better results.

To make that all this process became more efficient in terms of timing, we should think about the usage of a software; by one side it will minimize the engineers work during these documents conception and it also enables that for a certain elementary process, the complete know-how, customer complaints, problems and developed actions in different products are consolidate 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.

"as indicated in Figure 2 (Appendix)"

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.

"as indicated in Figure 3 (Appendix)"

8. Conclusions

To get a better design product, a DFMEA should be performed attending to all the characteristics associated to the manufacturing process. If the DFMEA is done during the design phase , corrections can be done attending to the identified gaps avoiding by this way 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 completion (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 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 are created at the order (see figure 4).

So, if all risks related to the product are identified in 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 by process, Control Plans makes possible to identify which items need to be controlled, how and by whom.

"as indicated in Figure 4 (Appendix)"

If all this analysis is done in the proper time of the project development or conception, lots of problems in production can be avoided, and consequently costs will be reduced.

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APPENDIX

Tables:

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

Table 1. FMEA History (Odom, 1995).

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

Table 2. Example of DFMEA contents.

Figures:

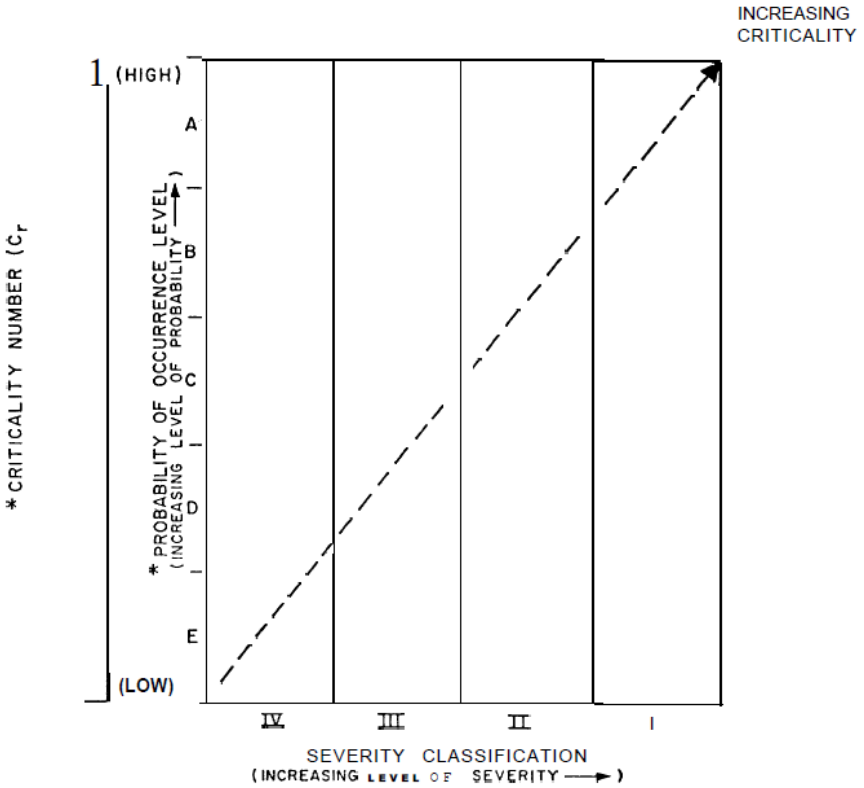

Figure 1. Example of criticality matrix (MIL-STD-1629A:1980).

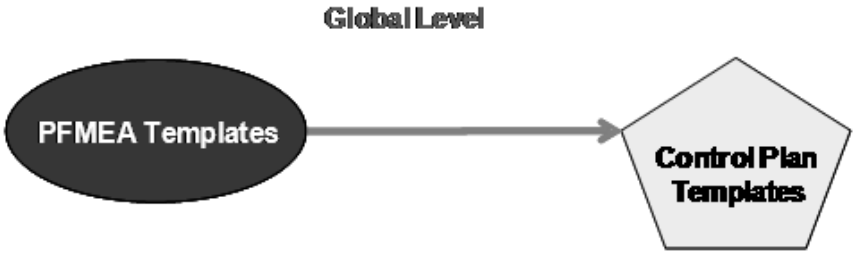

Figure 2. Templates development.

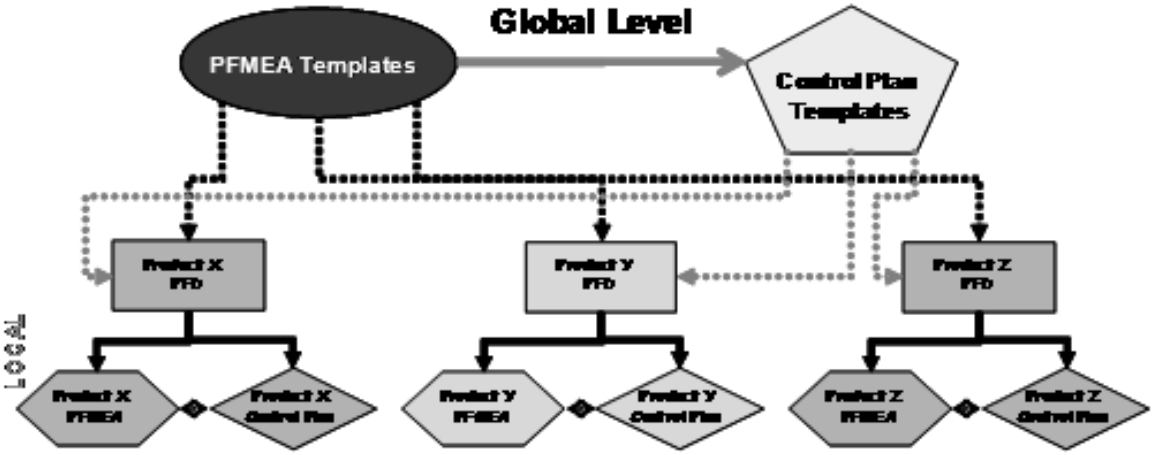

Figure 3. Conception of documents per product.

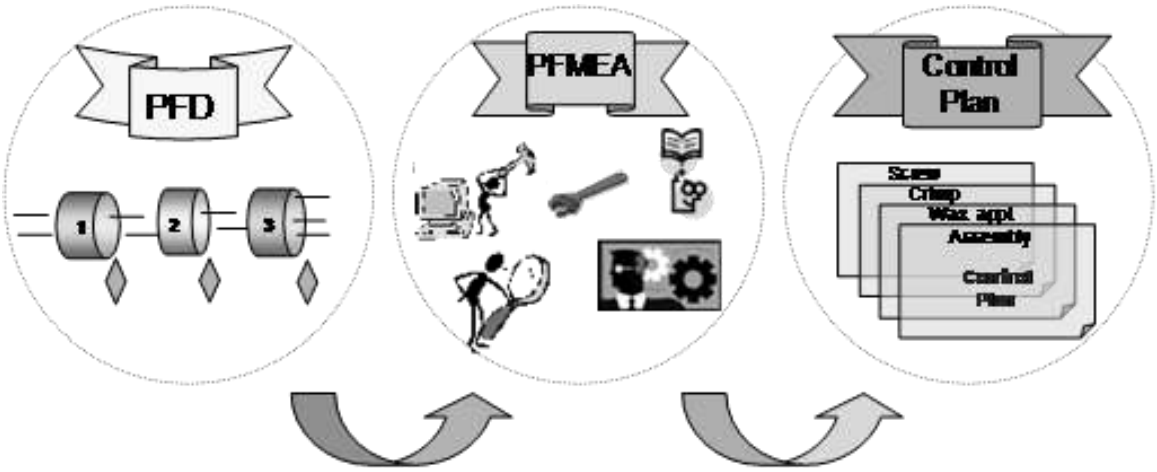

Figure 4. Connection between the manufacturing processes control documents.