Author: **Wenzel, Ben, D**
Title: ***Implementation of DFMEA methodology to improve the Design of Special Assembly Tooling***

The accompanying research report is submitted to the **University of Wisconsin-Stout**, **Graduate School** in partial completion of the requirements for the

Graduate Degree/ Major: **M.S. in Manufacturing Engineering**

Research Advisor: **Dr. Andy Pandian**

Submission Term/Year: **Fall, 2013**

Number of Pages: **53**

Style Manual Used: **American Psychological Association, 6th edition**

☒ **I understand that this research report must be officially approved by the Graduate School and that an electronic copy of the approved version will be made available through the University Library website**
☒ **I attest that the research report is my original work (that any copyrightable materials have been used with the permission of the original authors), and as such, it is automatically protected by the laws, rules, and regulations of the U.S. Copyright Office.**
☒ **My research advisor has approved the content and quality of this paper.**

STUDENT:

NAME Ben Wenzel **DATE: 12/3/13**

ADVISOR: (Committee Chair if MS Plan A or EdS Thesis or Field Project/Problem):

NAME **DATE:**

This section for MS Plan A Thesis or EdS Thesis/Field Project papers only
Committee members (other than your advisor who is listed in the section above)

1. **CMTE MEMBER'S NAME:** **DATE:**

2. **CMTE MEMBER'S NAME:** **DATE:**

3. **CMTE MEMBER'S NAME:** **DATE:**

This section to be completed by the Graduate School
This final research report has been approved by the Graduate School.

Director, Office of Graduate Studies: **DATE:**

Wenzel, Ben D. ***Implementation of DFMEA methodology to improve the Design of Special Assembly Tooling***

Abstract

In this study, the author successfully implemented a Design Failure Mode Effects Analysis (DFMEA) methodology to improve the design of special assembly tooling. The subject of the study was an existing trailer cart chosen because of the multitude of repairs that were required to keep the carts operational. The number and type of repairs were documented for 15 carts over a four week period. The DFMEA methodology was applied per the AIAG *Potential Failure Mode Effects Analysis FMEA 4th Ed.* reference manual. A cross-functional team of employees with expertise in the areas of Tooling, Manufacturing, Safety, Quality, Operations, and Production comprised the DFMEA team. Several meetings were held and the DFMEA form was filled out with RPNs assigned by the cross-functional team. Any cause of failure with an RPN value greater than a threshold of 40 was labeled a critical item and a corrective action was required for the cart redesign. The improvements and corrective actions suggested by the team reduced initial RPN values from over 300 to 40 and below. All corrective action improvements were incorporated into the redesigned cart resulting in significant reduction in repairs, which translated to annual cost savings of more than $130,000 for the company.

Acknowledgments

I would like to thank Dr. Andy Pandian, Program Director, M.S. in Manufacturing Engineering for accepting the role of advisor for this paper and for all his valuable input and time spent on its completion.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

The tooling department at XYZ Corporation is part of operations engineering. It is a resource for all other functional areas within operations engineering. These areas include: safety, manufacturing, assembly, quality, and ergonomics. The tooling department designs tools to meet the specific needs of these areas. There are different kinds of tooling that can meet the needs of these areas that generally exist in all manufacturing facilities. There are machine tools, general assembly tools that are purchased off-the-shelf, and there are those tools that are specifically designed for a single purpose and product design. It is the design of these special assembly tools that tool designers receive requests for on a daily basis and whose designs are subject to a variety of factors, which, if left unaccounted for will likely result in the failure of the tooling.

The process for developing special assembly tooling begins when a tool is needed for an assembly process and the requestor fills out a tool request form. The form has important information regarding the requirements of the tool. The form is then routed to an available tool designer who then attempts to fulfill the requirements of the request. It is the job of the designer to follow-up with the requestor to gather as much information as is needed to begin developing a concept design for the new tool. This information gathering could involve a phone call or meeting with the requestor and a trip to the area on the assembly floor to observe the process and discuss possible solutions with the employee who will ultimately use the new tool.

Once the information is gathered, the designer develops a concept tool design. If the concept design is approved, then a final design is created. After the final design is approved, detail drawings are completed. A determination is then made based on the current in-house tool room workload as to whether to build the tool in-house or outsource it to a local vendor. After the tool is complete, the designer contacts the requestor to let them know of its completion. The designer then takes the completed tool to the area where the tool is to be implemented to test whether it actually fulfills the requirements of the request. If the tool works to the satisfaction of all parties involved, it stays on the assembly floor and is added to the assembly work instructions. If it does not meet the requirements, it is reworked or redesigned until it does.

The current process by which the tooling department designs and creates tooling is sufficient enough to get tools made, however, it lacks an effective system for evaluating the potential factors that if left uncounted for, could result in tooling failures. Having a systematic method could effectively reduce the time it takes to design tooling and reduce tooling rework.

A tooling department can be a valuable asset to any manufacturing facility. Management at XYZ Corporation recognizes this and has taken a number of positive steps toward making the tooling department operate more efficiently. The one important area that has not been the subject of change, however, is the design process.

The design of special assembly tooling is very process specific. A proper assessment of the situation for which the tool is being requested is necessary. It is the duty of the tool designer to be familiar with the situation in which the tooling is to be used. When the tool designer assesses the situation on the assembly floor, it would be helpful to be aware of common failure risk factors that can influence certain aspects of the design.

One of the most widely used and successful tools for evaluating potential failures is a Failure Mode Effects Analysis or FMEA. The FMEA method rates factors such as, (O) occurrence, (S) severity, and (D) detection of potential failure modes and multiplies these values to obtain an RPN or risk priority number. Failure modes are prioritized according to their RPN value. Failure modes with RPNs greater than a predetermined threshold limit should be addressed from highest to lowest RPN value. XYZ Corporation currently uses FMEAs to evaluate potential product, process and project failures and eliminate them or reduce their risks. And, also to guide the creation of corrective action, process improvement, and risk mitigation plans. The company acknowledges that FMEAs create an opportunity for a multi-disciplinary critique of a design or process, and uncovers problems with the product that could potentially result in safety hazards, product malfunctions, or shortened product life. This leads to enhanced safety, reduced risk, and increased customer satisfaction. FMEAs, however, are not currently used at XYZ Corporation to evaluate potential specialty assembly tooling design failure modes.

Statement of the Problem

The lack of a structured system for evaluating potential special assembly tooling design failures has caused delays in delivery, rework, and re-design of tooling resulting in lost production time, quality defects and unsafe working conditions.

Purpose of the Study

The objectives of this study are to develop a FMEA method that will effectively evaluate the potential special assembly tooling failures, and to test whether that method has a significant positive impact on the design of the tool.

Assumptions of the Study

The assumptions of this study are:

1. The individuals qualified to make tool requests are familiar enough with processes and products to determine when a tool is required to solve a problem.
2. XYZ Corporation will continue to recognize FMEA as a valid tool for assessing potential problems.
3. XYZ Corporation will continue to insource tooling design.

Definition of Terms

Tool Design. "Tool design is a specialized area of manufacturing engineering comprising the analysis, planning, design, construction, and application of tools, methods, and procedures necessary to increase manufacturing productivity (Nee, 2010, p. 1)."

FMEA. "FMEA is an analytical methodology used to ensure that potential problems have been considered and addressed throughout the product and process development process (Chrysler LLC, Ford Motor Company, General Motors Corporation, 2008, p. 2)."

Failure Mode. "Physical description of a failure. It is the manner in which the process fails to perform its intended function (Kumar et al., 2011, p. 5289)."

Failure Effect. "It is an impact of failure on process or equipment. It is an adverse consequence that the customer/user might experience (Kumar et al., 2011, p. 5289)."

Failure Cause. "It refers to the cause of failure (Kumar et al., 2011, p. 5289)."

Severity (S). Severity measures the seriousness of the effects of a failure mode. Severity categories are estimated using a 1 to 10 scales (Kumar et al., 2011, p. 5289)."

Occurrence (O). Occurrence is related to the probability of the failure mode and cause (Kumar et al., 2011, p. 5289)."

Detection (D). The assessment of the ability of the "design controls" to identify a potential cause (Kumar et al., 2011, p. 5289)."

Risk Priority Number (RPN). The Risk Priority Number is the product of the Severity (S), Occurrence (O), and Detection (D) ranking. The RPN is a measure of design risk and will compute between "1" and "1000" (Kumar et al., 2011, p. 5289)."

Methodology

The remainder of this paper is as follows: Literature Review, Methodology, Results, and Discussion. The next section is the review of the related literature where articles on the topic of this study will be summarized and critiqued. Following the literature review is the methodology section of the paper which describes the methods for conducting the study. After the methodology section is the results section where the findings of the study are reported. And lastly, the conclusion section states the implications of the findings.

Chapter II: Literature Review

The design of special assembly tooling must take into consideration a number of important factors such as, safety, ergonomics, and process improvement. Not all of these factors can be equally addressed with the design of the tooling. If the failures of the tooling could be prioritized, then the design factor which would most likely lead to the greatest probability of failure would get the most attention. XYZ Corporation does not currently have a structured method for addressing the failures of special assembly tooling. The purpose of this study is to develop a FMEA method for the design of special assembly tooling and test the effectiveness of that method. The information in the following literature review was used in the development of the special assembly tooling design FMEA.

History of FMEA

The origin of FMEA. The concept of failure mode effects analysis FMEA was first created in 1949 by the United States Army (Namdari, Rafiee, & Jafari, 2011). In the 1950s, the aerospace industry adopted and further developed the FMEA methodology, and because of its systematic approach to proactively identifying potential design failures, its use eventually spread to other industries, such as manufacturing, banking, human resources and healthcare (Namdari et al., 2011).

The development of FMEA. FMEA can be adapted to assess the risks of potential failure modes of many different applications; therefore, its use can be tailored to meet the specific needs of a variety of industries. Although FMEA was originally created by the U.S. Army, it was soon after adopted by the aerospace industry because of its inherent value as a method for effectively identifying potential failure modes (Namdari et al., 2011).). The U.S. Army has a long history of pushing its contractors to be more innovative (Hounshell, 1984).

Beginning as early as the late 1800s, the U.S. Army challenged the firearms manufacturers to create rifles with interchangeable parts that would make repairs done on the battlefield more successful (Hounshell, 1984). The U.S. Army had identified a potential failure mode of their rifles. Not being able to make repairs to rifles on the field of battle put soldiers' lives at risk. When soldiers' lives depended on the reliability of the equipment they provided, the U.S. Army responded by identifying the failure and enacting measures to correct it. FMEA was no doubt a result of a number of these scenarios repeated over time each adding to the accumulated knowledge of the previous one until a systematic method for identifying potential failure risks was developed even before the design phase was begun. The U.S. Army created a powerful tool to aid them in the design of their equipment.

Applications of FMEA

Traditional FMEAs provide a generalized process for assigning risk priority to potential failure modes. Since the creation of FMEA, practitioners have developed ways to alter the traditional FMEA model to more closely fit their particular area of interest.

FMEA use in design. Ling, Hsieh, and Cowing (2005) used DFMEA in conjunction with other tools to design and develop reliability into the Light Duty Dodge® Ram Chassis. Weaknesses within in the chassis design were located using DFMEA. DFMEA was especially effective at revealing design issues in the early stages of product development when a prototype may not be available for testing (Ling et al., 2005). DFMEA, in this case, proved to be an important tool for designing reliability into the product.

Popovic, Vasic, and Petrovic (2010) used a modified FMEA method for decreasing failure risks in bus body designs. Their new method not only addressed potential failure modes, but also factored in the financial cost of those failure modes. By adding factors into the traditional FMEA model, such as labor rates and part costs, they were able to satisfy the end user, make improvements to time and cost, and more effectively communicate potential risks to team members, suppliers, management, and clients.

FMEA use for process optimization. In manufacturing, FMEA worthy processes are those that can impact the manufacturing and assembly operations, such as shipping, receiving, transporting of material, storage, conveyors or labeling (Chrysler LLC, Ford Motor Company, General Motors Corporation, 2008). Process FMEA or PFMEA supports manufacturing by reducing the risk of failures in process development (Chrysler et al., 2008). PFMEA reduces the risk of failures by identifying and evaluating process function and requirements, potential product and process failure modes and effects, and how they will impact the process and customers (Chrysler et al., 2008).

McCain (2006) developed an alternative approach to the traditional FMEA methodology for a service delivery process. This specific service was to ensure that a steady flow of contract employees would be available to meet the assignment terms of the customers.

In order to accomplish this, McCain (2006) needed to develop a customer needs clarification spreadsheet. Once these needs were identified, the project team conducted a brainstorming session to determine the potential failure modes that would affect the process for meeting the customer needs. Project team brainstorming was an essential part of the development of the FMEA model, as it was used routinely in the formulation of different factors, such as how the severity of the failure impacts the customer and to identify potential causes of failure modes. McCain (2006) noted that the involvement of the customer in the brainstorming sessions was necessary to adequately identify the severity of failures.

In order to develop the occurrence rating, McCain (2006) chose the process with the highest productivity rate. That means that this process would potentially have the highest probability of failure occurrence due to it being performed more frequently than other processes. By implementing an FMEA and addressing the customer needs, McCain (2006) was able to lower the occurrence rating and the detection rating of failure modes.

It is important to note that the steps to lower the occurrence and detection ratings were repeated for all customer needs documented in the clarification spreadsheet. This particular point in the methodology alludes to the fact that FMEA is an iterative process. It is necessary for the project leader to revisit the FMEA whenever a process has changed (McCain, 2006).

Continuous improvement is a concept that is mainly associated with the improvement of manufacturing processes. However, the continuous improvement concept is just as important and transferrable to service processes. According to McCain (2006), FMEA is a useful tool for identifying continuous improvement opportunities in service processes. The important steps in determining these improvement opportunities are to identify the processes that have the largest effect on the customer, use FMEA to determine what features of the process have the highest RPN, and create a Pareto chart to rank the RPNs (McCain, 2006).

Kumar, Jethoo, Pandel, and Poonia (2011) used the FMEA method in a foundry setting to determine which of the steps in the core making process that contribute the most to rejections. Before the FMEA method was applied to the core making process a flow chart was created of the manufacturing process steps. FMEA was applied as a team function with members from production, quality, maintenance and a FMEA expert. Data was collected pertaining to core rejection from QC reports. Using a standard FMEA form, RPNs were obtained and evaluated based on a scale of 1-10. Problem areas were identified with the information the team had gathered. Focus was concentrated on these problem areas and corrective actions were implemented. Original RPN values were compared to the recalculated RPN values obtained after implementing the corrective measures. By using the *Potential Failure Mode and Effects FMEA* manual FMEA method, the team was able to lower the RPN values and lower core rejection by 36%.

This study is an example of an unaltered traditional FMEA method. Kumar et al. (2011) used the FMEA protocol outlined in the *Potential Failure Mode and Effects Analysis FMEA* manual and were able to reduce the rejections. In this case, the traditional FMEA method was sufficient enough to achieve the desired outcome. No mention was made of the shortcomings described by other studies on FMEA methodology. Kumar et al. (2011) did state that they were able to evaluate the impact of these problems based on core rejections or lost production volume and financial loss. This may have been the means used to correct the subjectivity inherent in the traditional FMEA RPN calculation method.

FMEA use in business decisions. FMEA can also be applied to the analysis of risks involved in making important business decisions. One such decision that seems to be common among U.S. manufacturing companies is whether or not to outsource business to other countries. Welborn (2007) has documented a method using FMEA for the purpose of assessing the potential risks involved with outsourcing. Many companies have realized gains from outsourcing; however, there are potential risks involved, as well (Welborn, 2007). Risks associated with supply chain and outsourcing, such as unexpected cost, extended lead times, poor quality or other negative performance variables are part of a relatively new subject area (Welborn, 2007). Ultimately, Welborn (2007) was able to prioritize failure modes by using RPN numbers developed by a cross-functional team and control risks ahead of time resulting in low risk supply chain integration.

FMEA use in maintenance. Cotnareanu (1999) developed FMEA into a maintenance tool. This maintenance FMEA tool, which is to be used in high volume specialized processes, should be developed by a team consisting of a maintenance manager, engineers, mechanics, and electricians, with the leadership falling to the maintenance representative (Cotnareanu, 1999).

Cotnareanu (1999) differentiates the consequences of tooling failures from equipment failures. Since tooling is a more product specific element of manufacturing, and assuming a company manufactures a number of similar products each with its own set of tooling, a failure in tooling may only stop the production of a limited number of products. Equipment failures, on the other hand, are normally not product specific and are required in the performance of general manufacturing operations. For example, an overhead crane in a manufacturing cell is a piece of equipment whose general use is to lift heavy and/or large items up from a stationary position. If this piece of equipment were to fail, certain parts could not be lifted and maneuvered into its proper assembly location. This breakdown would affect all product lines whose assembly would require crane assistance in that particular manufacturing cell.

Defining the customer is an important pre-requisite to the development of FMEAs. In a PFMEA, the customer would normally be the end user, but could also be a downstream manufacturing operation or service operation (Chrysler et al., 2008). In the maintenance FMEA, since maintenance is a service provider supporting production, the end user is production (Cotnareanu, 1999). Production workers use the equipment that maintenance services on a daily basis, which is why it is so important to recognize them as the customer. Not only do they rely on the proper functioning of the equipment to do their jobs, but they are also the most familiar with its operating condition. It is for this reason, that the customer be involved with the FMEA process as a member of the cross-functional team because no one else has as much intimate knowledge about the equipment, its uses, and the processes in which it is being used.

A traditional FMEA can be developed by whatever methods a project team would determine. However, there are some common components to the process of developing an FMEA. If you are following along with the traditional FMEA development process, the next element to consider is the scope, which sets the limits of the FMEA analysis (Chrysler et al., 2008). According to Chrysler et al. (2008), the scope must be determined at the onset of FMEA development process. The scope gives the FMEA analysis its focus of what to include and what to leave out and what will be evaluated because sometimes what gets left out in an FMEA is just as critical as what is left in (Chrysler et al., 2008). Cotnareanu (1999) in his work on the development of the maintenance FMEA, does not specifically state the scope of the analysis. It is understood that equipment, as defined by Cotnareanu (1999), is any general equipment that is not product specific, but whose failure would result in the inability to manufacture products until the problem is resolved. Cotnareanus' (1999) analysis would benefit from scope definition.

Chrysler et al. (2008) breaks up the scope of an FMEA into three types: system, subsystem, and component. A system FMEA, from a maintenance perspective would be all cranes used to provide lifting assistance for production. A subsystem, using the same example, would be all the cranes used to assemble the chassis of a vehicle. At the component level, the scope might include a crane at one particular station on the assembly line. Defining the scope and developing the maintenance FMEA for all three levels of scope definition, may result in a more comprehensive maintenance system.

Chrysler et al. (2008) has provided a process to develop an FMEA. Although the process is comprehensive and can be used in its original format, not all project teams have strictly adhered to this format. In some instances, FMEA practitioners have developed a FMEA process to suit their specific project needs. Some aspects of the traditional FMEA model have been omitted which others have found it beneficial to add to the process. Cotnareanu (1999) developed an FMEA process model that excluded the scope definition prerequisite described in the Chrysler et al. (2008) FMEA process model. No specific reason is given for the exclusion of the scope definition prerequisite from Cotnareanus' FMEA model. Cotnareanus' (1999) maintenance FMEA model also differs from the traditional model in that it includes a definition of short- and long-term goals. Although the traditional FMEA does not include the definition of short- and long-term goals, it does attempt to develop actions and controls that mitigate potential failure modes. Eliminating the failure modes that would derail any attempts to meet short- and long-term goals is the purpose of developing an FMEA. If short- and long-term goals are not clearly defined, then it becomes very difficult to determine a direction for continuous improvement efforts.

FMEA use in organization improvement. Karaulova, Kostina, and Sahno (2012) proposed using fuzzy FMEA as a method for prioritizing organizational performance drivers. Organizations that seek to improve must be able to recognize which areas of the organization that need improving. Organizational leaders, however, must also be able to prioritize the performance drivers that will result in the greatest improvement. Without knowing the importance of certain performance drivers, scarce resources could be misallocated. Questionnaires were administered to experts to determine what the performance drivers were.

Fuzzy RPN values were then calculated by multiplying severity, occurrence and detection rates. Improvement projects were then selected based on the fuzzy RPN values.

Karaulova et al. (2012) concluded that this method was effective in prioritizing potential projects intended to improve the organizations performance. This study provided an example of how a modified FMEA method can be applied to a problem in conjunction with other tools to give an organization a clear direction for driving improvements.

FMEA use in complex systems. FMEA has also been used to identify hardware and software failure modes and criticality. Previously, only hardware failure modes and criticality had been analyzed using FMEA (Putcha et al., 2008). The software in this case needed to respond to the hardware failure modes in such a way as to not cause system failure, and any failure in the system function is considered a failure mode of the software (Putcha et al., 2008). Putcha et al. (2008) determined that FMEA was not only a powerful tool for analyzing the failure modes and criticality of hardware, but it is also effective as a means for analyzing the failure modes and criticality of software. In this study of the use of FMEA to analyze hardware and software failure and criticality modes, it was the interaction between the two FMEAs that resulted in the most important findings (Putcha et al., 2008). This study demonstrates the usefulness of FMEA to analyze complex system reliability through the interactions of hardware and software failure modes and criticality analyses.

Traditional FMEA Pitfalls

The traditional FMEA model is not without drawbacks. In the previous section, studies demonstrating the effectiveness of different variations to the traditional FMEA model were reviewed. The studies in the following section illustrate the shortcomings and pitfalls of the traditional FMEA model and the steps taken to correct them.

Inaccurate risk prioritization. The shortfalls of the traditional FMEA method of prioritizing failure risk are prevalent in the literature. The Risk Priority Number (RPN) is in most cases the focal point of the FMEA studies in the literature. The purpose of these studies is to attempt to overcome the inherent problem with the traditional FMEA RPN by establishing and testing different methods for determining risk priority. Many of these studies follow the same basic format of describing what FMEA is, what its shortcomings are, the method(s) for correcting that shortcoming, and a case study to test the effectiveness of that method. The format for the following section of the literature review will include a description of the proposed methods for fixing the risk prioritization problem in the traditional FMEA method, a description of the problem as seen from the perspective of the author(s), and a critique of the proposed new method for prioritizing risk.

Niezgoda and Johnson (2007) acknowledged the drawbacks of the traditional DFMEA method by stating in their study that the RPN values obtained are subjective and do not necessarily represent specific numerical quantities. Niezgoda and Johnson (2007) agree with most of the literature in that the traditional DFMEA method has shortcomings. These shortcomings pertain to the method for determining the RPN values and how these values are sometimes unrepresentative of the true risk potential of the failure modes.

Not involving the right people. Ramu (2009) outlines some of the problems one can face in the development, implementation, and sustainability phases of the traditional FMEA method. Not having subject matter experts during the development of the FMEA who can properly ascertain what the failure modes are and their relative importance can put the effectiveness of the FMEA at risk. Not having these individuals inputs can hinder the success of the FMEA. Inadequate planning and ignorance of who the experts are before gathering team members for the brainstorming session obstructs FMEA development.

Methods for Correcting Traditional FMEA Issues

Setting values for O, S, and D. To reduce the subjectivity of the RPN values, Niezgoda and Johnson (2007) suggest establishing the criteria for calculating its value and its meaning concerning corrective actions to take toward improving the design. Prior to the analysis, numerical values for O, S, and D must be set. Corrective actions must be linked to RPN value ranges that have thresholds and cutoff points that delineate these ranges. The consistent use of these predetermined values for O, S, and D throughout the DFMEA operation can negate the subjectivity and uncertainty in the resultant RPN.

Niezgoda and Johnson's (2007) approach to the problem differs in comparison to much of the literature on the subject. Many studies have been done to test the effectiveness of a new, modified or supplemented DFMEA model. Niezgoda and Johnson (2007), however, propose that the traditional RPN calculation method can be more effective if the criteria for establishing the value is based on an initial determination of values for O, S, and D and that those values are used consistently throughout the DFMEA iterations.

Using a fuzzy approach. Sofyalioglu and Ozturk (2012) have attempted to ameliorate the shortcomings of the traditional FMEA approach by augmenting it with the Grey Relational Analysis and Fuzzy Analytic Hierarchy Process (FAHP). The intended use of these tools is to produce an estimated weight for the risk factors.

Arabzad, Ghorbani, and Razmi (2011) used FMEA combined with a variety of techniques to serve as a strategy for the effective management of purchasing and supply. Arabzad et al. (2011) collaborated with decision-makers within the company to determine some criteria in the areas of risk and profit. More qualitative data was gathered from records kept by various departments. Arabzad et al. (2011) also developed a questionnaire based on the FMEA method, which was given to decision-makers to determine the risk criteria. Fuzzy RPN was used to measure the associated risk criteria based off the Occurrence, Severity, and Detection values set by the decision-makers and their experience from supply profit impacts.

Karaulova et al. (2012) proposed using fuzzy FMEA as a method for prioritizing organizational performance drivers. Organizations that seek to improve must be able to recognize which areas of the organization that need improving. Organizational leaders, however, must also be able to prioritize the performance drivers that will result in the greatest improvement. Without knowing the importance of certain performance drivers, scarce resources could be misallocated. Questionnaires were administered to experts to determine what the performance drivers were. Fuzzy RPN values were then calculated by multiplying severity, occurrence and detection rates. Improvement projects were then selected based on the fuzzy RPN values.

Karaulova et al. (2012) concluded that this method of was effective in prioritizing potential projects intended to improve the organizations performance. This study provided an example of how a modified FMEA method can be applied to a problem in conjunction with other tools to give an organization a clear direction for driving improvements.

Keskin and Ozkan (2008) created a method called Fuzzy Adaptive Resonance Theory (Fuzzy ART) to address the shortcomings of the traditional FMEA method of evaluating risk priority. ART was originally designed for the analysis of human cognitive function to map input vectors in a complex environment to clusters labeled according to a specific term that has meaning for all the input vectors mapped to that cluster. Fuzzy ART was developed to combine aspects of the original ART method into a more simplified framework. In this study, Fuzzy ART was utilized on FMEA where RPNs are clustered accordingly. One of the main benefits of the Fuzzy ART FMEA method is that it only requires the use of a small program and does not require an expert to implement it.

Combining FMEA with other tools. Once the RPN values were Defuzzied and the final RPN values obtained, Arabzad et al. (2011) used an MCDM technique called Entropy to assign an importance weight to the criteria. TOPSIS, another MCDM technique, was then used to classify supply risk and profit impact into four categories, each of which indicates a clear-cut approach to implementing a supply-based strategy. Arabzad et al. (2011) found this proposed method to be effective in selecting suppliers based on classified profit impacts. Not only can appropriate suppliers be selected with this model, but bargaining power and substitution are also obtainable. This method of using FMEA and MCDM tools is unique in that it is used to determine a supply strategy based on risk criteria RPN values. This study is another example of the diverse applications of the FMEA method. FMEA can be a stand-alone method for prioritizing failure risk, or it can be combined with other tools as part of a larger strategy for prioritizing and classifying.

The findings from the literature review demonstrate that the FMEA model is not constrained to any specific type of application. As the literature has shown, the traditional FMEA model can be improved upon and is a tool that can be used in many different applications. FMEA has also proved to be a powerful general prioritization tool that can be used in many different applications and industries.

Chapter III: Methodology

The objectives of this study are to develop a DFMEA method that will effectively evaluate the potential special assembly tooling failures, and to test whether that method has a significant positive impact on the design of the assembly tool. The lack of a structured system for evaluating potential special assembly tooling design failures has caused delays in delivery, rework, and re-design of tooling resulting in lost production time, quality defects and unsafe working conditions. The proposed method used to improve the design of the tooling is the Design Failure Mode Effects (DFMEA) Analysis tool described by Chrysler et al. (2008).

Cart Design and Assembly Procedure

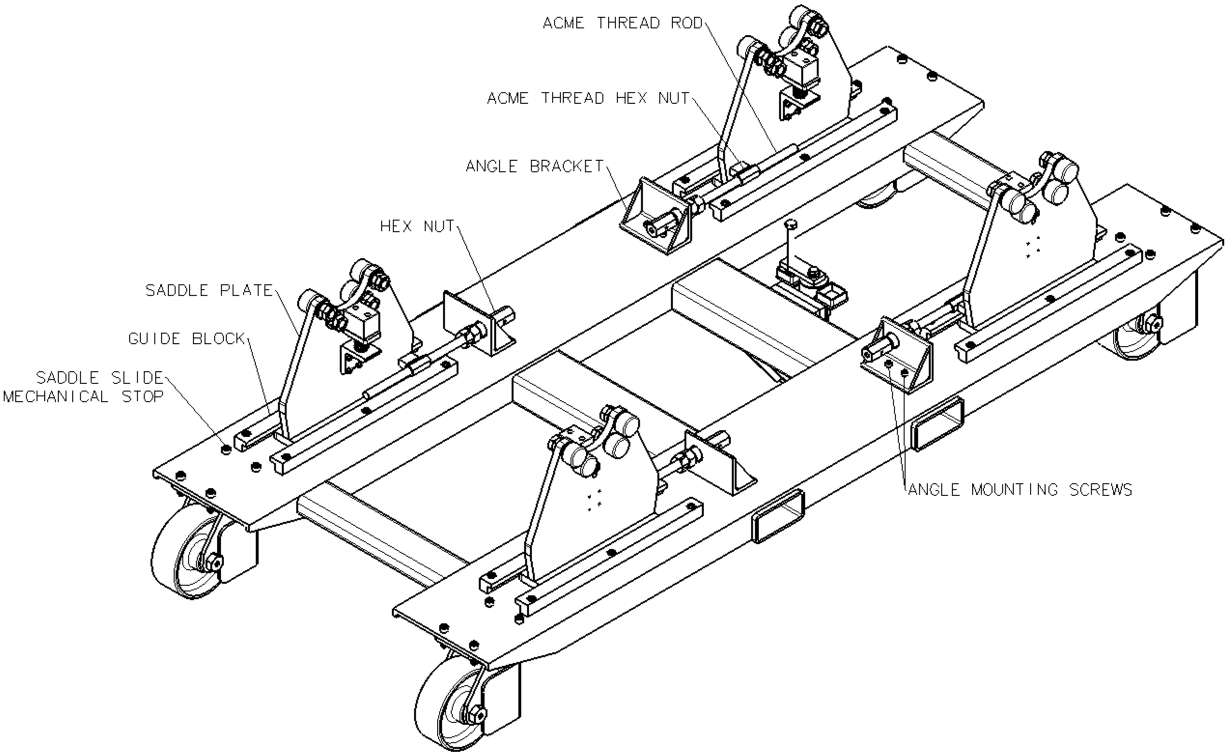


Figure 1. Trailer cart design before modifications derived from DFMEA.

The test subject shown in *Figure 1* is an existing trailer assembly line cart. The carts are used to hold the components of a large military trailer as it is being assembled. The cart supports the five ton trailer by the axles. The axles are assembled independently and are then placed on the cart. Because the trailer is built from the bottom up, the suspension leaf springs are not under load. When the trailer cargo body is lowered onto the axle springs, the axles need to be spread apart in order to bring the cargo body down into the correct position to fasten the cargo body onto the axles.

The carts have been designed to allow the axles to be moved forward and back independently of each other. The saddles on the cart that the axles rest on are adjustable. The saddles slide back and forth and are held down between two fixed mounted guide brackets. An Acme threaded nut is welded to the inside of the saddle plate. An Acme threaded rod connects the saddle to a fixed mounted angle bracket. One end of the Acme rod is threaded through the Acme nut welded to the saddle. The other end of the Acme rod passes through a bushing in the angle bracket. A hex nut is attached to the section of rod that extends through the angle bracket.

In order to move the saddles back and forth with the axles resting on them, the assemblers use a pneumatic impact gun. The impact gun is equipped with a hex socket the same size as the hex nut on the Acme rod. The rod is rotated through the welded hex nut threads on the saddle. This forces the saddle to move along the length of the Acme rod.

Assembly Issues

The carts are rejected in most instances because of stripped threads on the Acme rods due to the overuse of the impact gun used to adjust the position of the saddles. The saddles are allowed 8.5” of travel. Mechanical stops prevent the saddle from sliding beyond this length. Before the saddles have reached these mechanical stops, the assembler should stop using the impact gun to adjust the saddles. In some cases; however, the assemblers continue to run the saddles up against the stops with the impact gun. Continued use of the impact gun, which is capable of up to 700ft-lbs of torque when less than 50ft-lbs is required to adjust the saddles, after the saddles have reached the stops causes the Acme threads on the rods to strip. Not only do the threads on the rod strip, but also overuse of the impact gun causes the threads in the Acme nut welded to the saddle to strip. Furthermore, because of the high amount of force applied by the impact gun, the mounting hardware (highlighted in Figure 2 below) fastening the angle bracket to the cart strips out the threads in the cart.

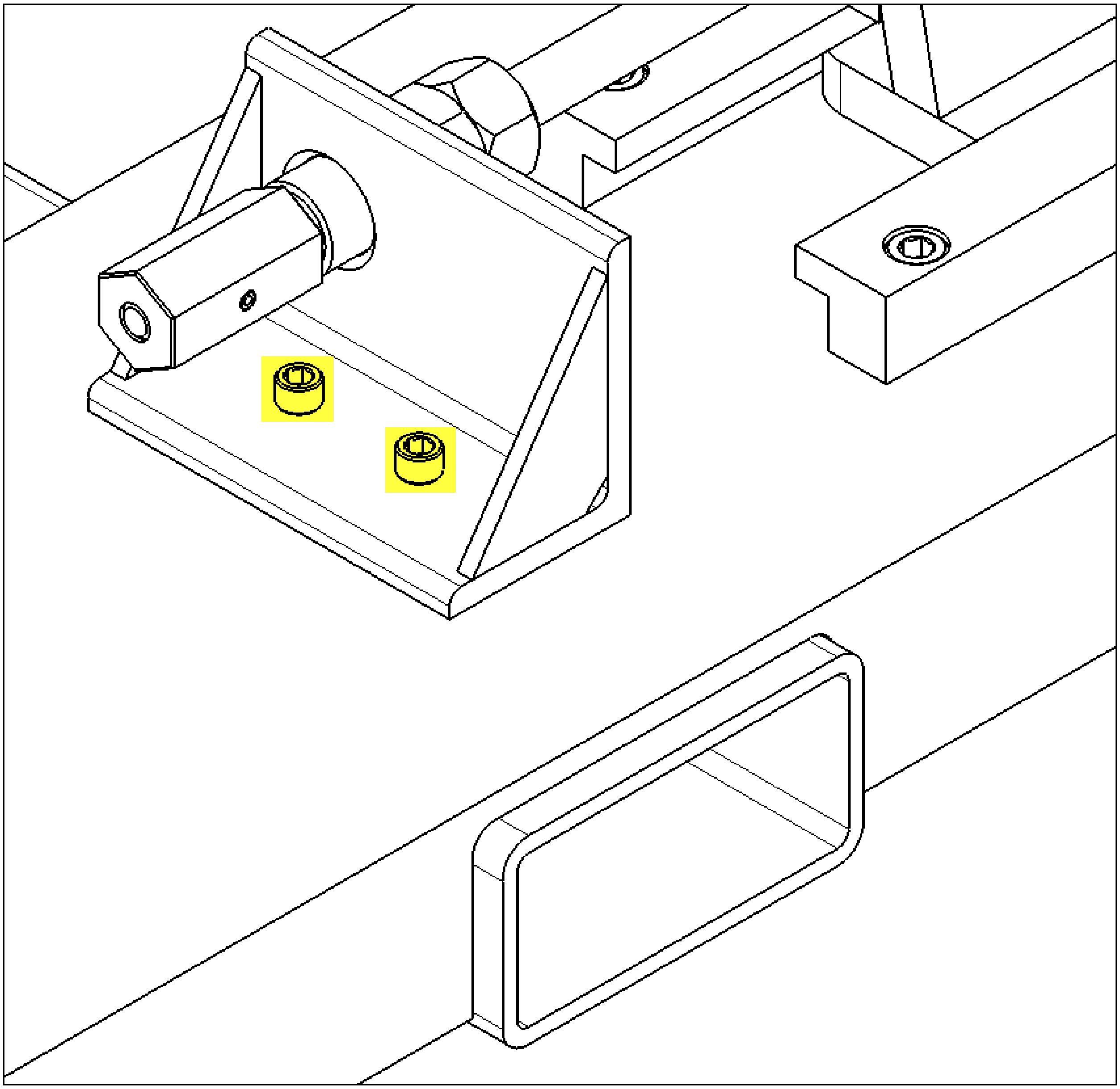
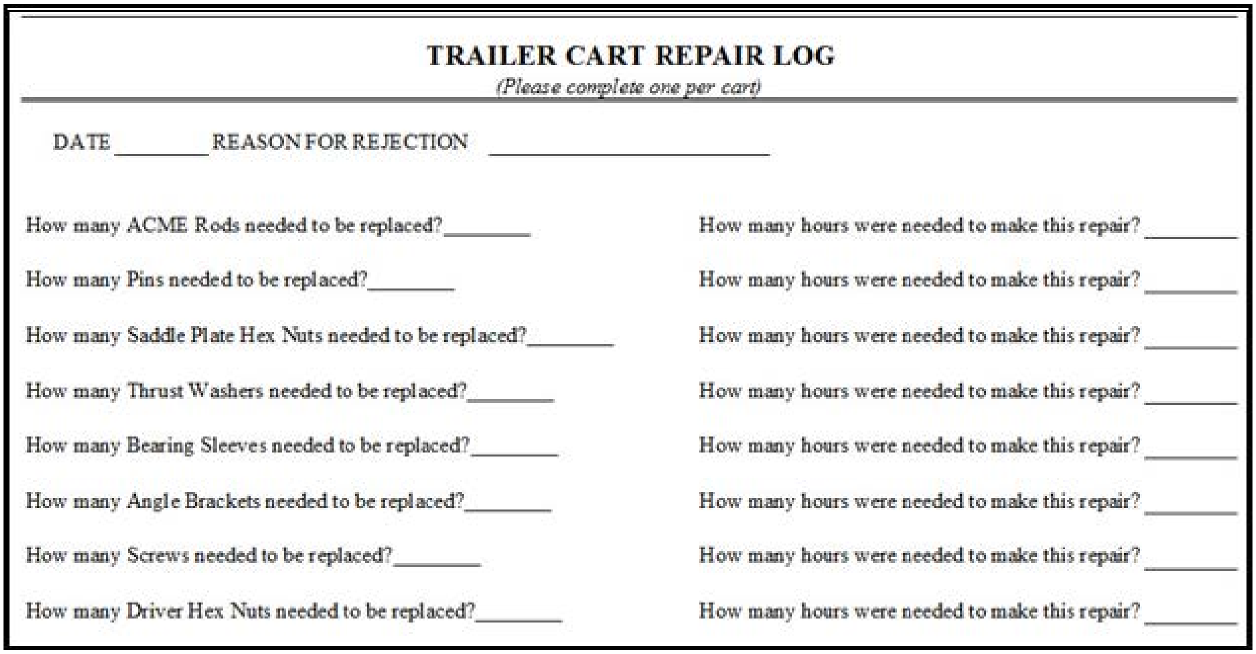


Figure 2. Angle bracket mounting hardware.

Data Collection



TRAILER CART REPAIR LOG

(Please complete one per cart)

DATE ________ REASON FOR REJECTION ________________________

How many ACME Rods needed to be replaced?________	How many hours were needed to make this repair? ________
How many Pins needed to be replaced?________	How many hours were needed to make this repair? ________
How many Saddle Plate Hex Nuts needed to be replaced?________	How many hours were needed to make this repair? ________
How many Thrust Washers needed to be replaced?________	How many hours were needed to make this repair? ________
How many Bearing Sleeves needed to be replaced?________	How many hours were needed to make this repair? ________
How many Angle Brackets needed to be replaced?________	How many hours were needed to make this repair? ________
How many Screws needed to be replaced?________	How many hours were needed to make this repair? ________
How many Driver Hex Nuts needed to be replaced?________	How many hours were needed to make this repair? ________

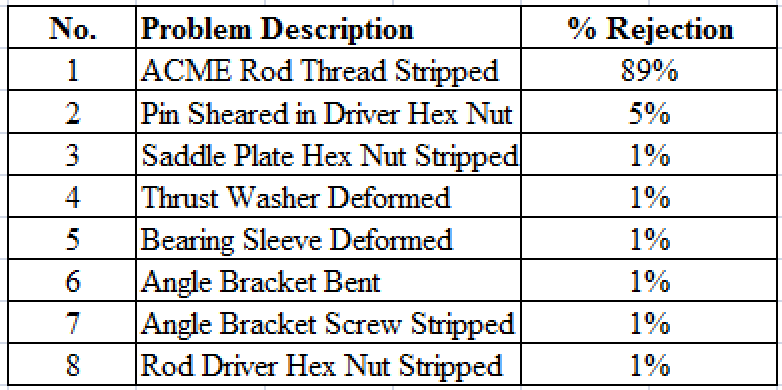
Figure 3. Repair log used to collect quantity of parts replaced per cart and time needed to replace those parts.

When a trailer cart became damaged to the point that the assemblers could no longer operate it, the assemblers attached a reject tag to the cart and moved it to the material handler pick-up staging area. A material handler would identify the reject tab and transport the cart from the staging area to the on-site weld shop where the welder inspected and repaired the cart. The welder used a repair log (Figure 3) to document the parts that were needed to be replaced and the time required to replace them. This process was repeated for all trailer carts needing repairs for a period of four weeks. The data collected from the logs showed that an average of 2 carts needed repairs per week. Table 1 below lists the problems with the carts that were causes for rejection and their percentages.

Data Analysis

Table 1

Cart Rejection Details



No.	Problem Description	% Rejection
1	ACME Rod Thread Stripped	89%
2	Pin Sheared in Driver Hex Nut	5%
3	Saddle Plate Hex Nut Stripped	1%
4	Thrust Washer Deformed	1%
5	Bearing Sleeve Deformed	1%
6	Angle Bracket Bent	1%
7	Angle Bracket Screw Stripped	1%
8	Rod Driver Hex Nut Stripped	1%

The data that was collected over the 4 week period represented in Figure 4 clearly shows that the great majority of rejections were caused by the threads being stripped on the Acme rods. Since 89% of the cart rejections were from stripped threads on the ACME Rod, the DFMEA effort was focused on the possible causes of this failure.

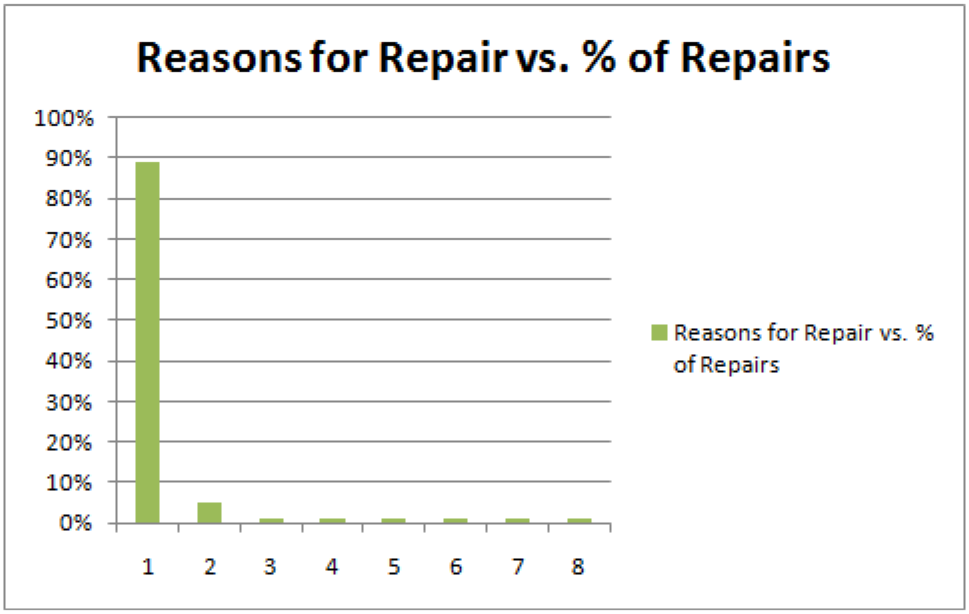
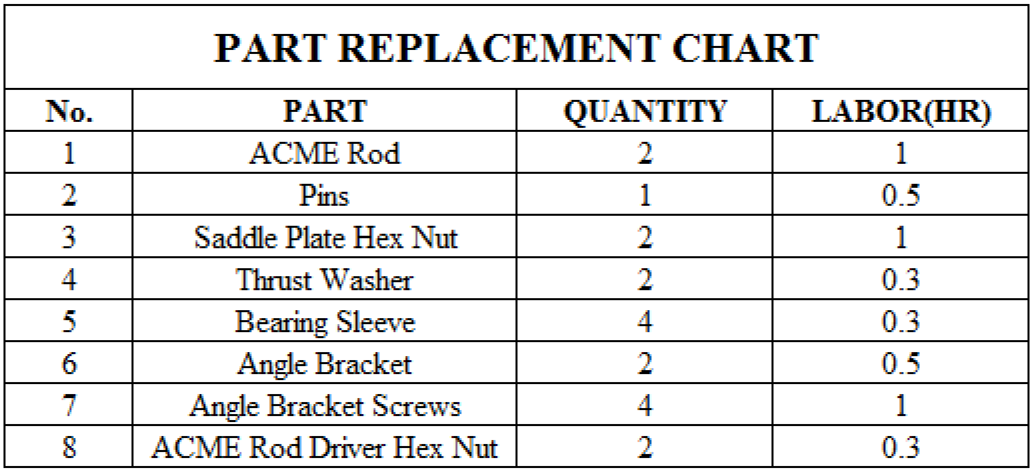


Figure 4. Reasons for rejection of carts.

In addition to the reasons for the rejection of the carts, the Repair Logs collected data on the parts that needed to be replaced, their quantities and the time required to replace them. The data was then used to get an average of the quantity and labor time needed to replace the parts per cart, as shown in Table 2 below.

Table 2

Replacement Part Quantities and Labor Averages Per Cart



PART REPLACEMENT CHART

No.	PART	QUANTITY	LABOR(HR)
1	ACME Rod	2	1
2	Pins	1	0.5
3	Saddle Plate Hex Nut	2	1
4	Thrust Washer	2	0.3
5	Bearing Sleeve	4	0.3
6	Angle Bracket	2	0.5
7	Angle Bracket Screws	4	1
8	ACME Rod Driver Hex Nut	2	0.3

DFMEA Implementation

A cross-functional team was formed as the first step of the DFMEA process, as prescribed in the AIAG *Potential Failure Mode Effects Analysis FMEA 4th Ed.* reference manual. The team for this study was composed of the Tooling Manager, who was designated as the project manager responsible for managing and tracking FMEA action items, the Tool Designer, who acted as the FMEA Facilitator responsible for creating and maintaining FMEA documentation, organizing and leading FMEA meetings and maintaining the scope and focus of the FMEA, and FMEA Participants including the Safety Manager, a Quality Engineer, a Production Worker, and an Industrial Engineer.

The DFMEA team used the data collected from the Repair Logs to identify the failure mode(s) to focus the DFMEA effort. As the data clearly indicated, the main failure mode responsible for nearly 90% of all rejections of the carts by assembly was the threads stripping on the ACME Rods, which renders the carts inoperable.

Before potential causes of the failure mode were discussed by the team, the scope of the DFMEA was defined by using a block diagram (Figure 5) which represents the components in the design of the trailer cart and their interaction with one another. The dashed line box encompasses the parts/assemblies that were included in the scope of the DFMEA, and those outside the box were not considered relevant to the analysis. The block diagram helped to narrow the focus of the team brainstorming session to the cart design components that could have a direct or indirect impact on the failure mode of the cart.

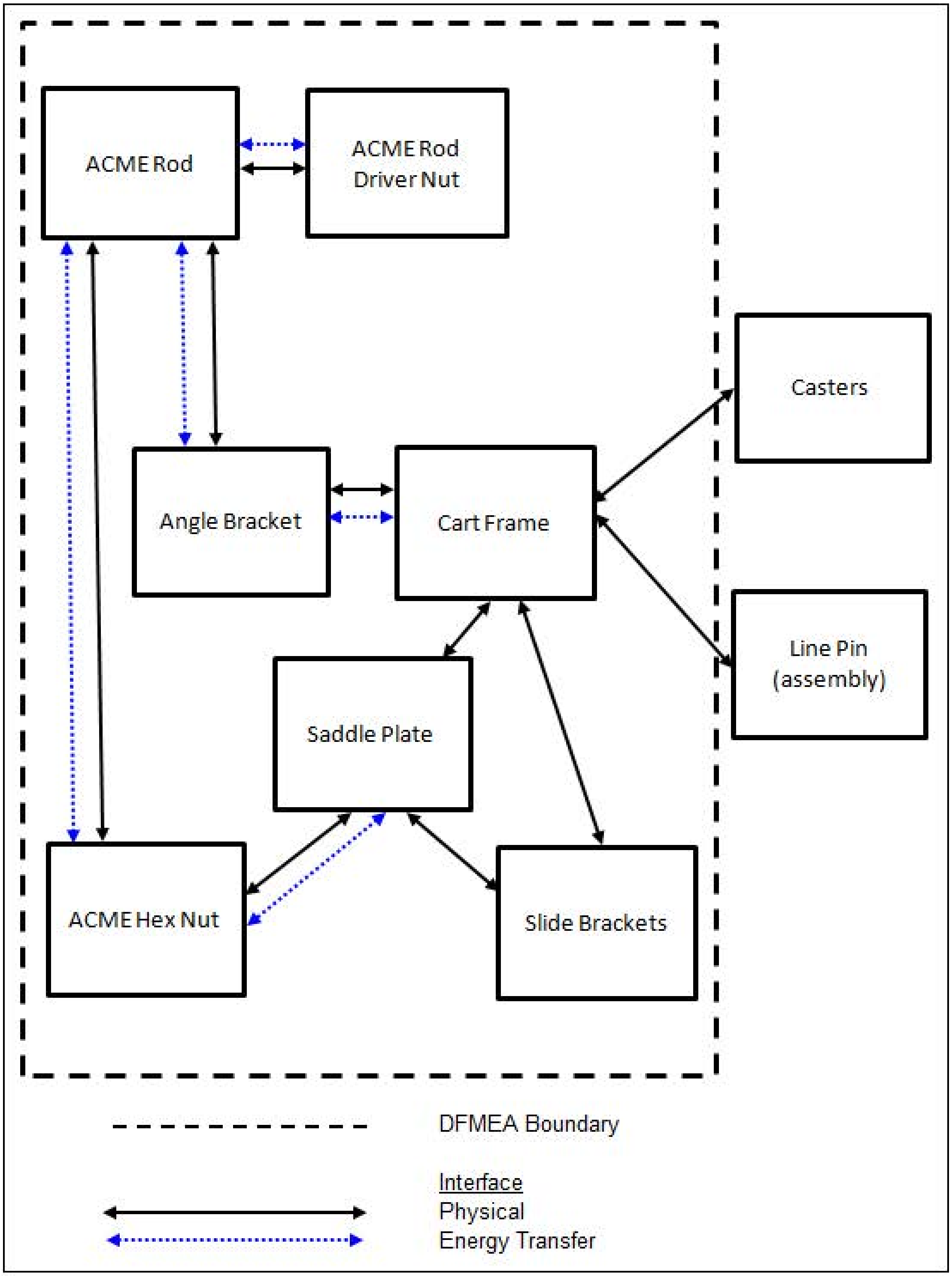


Figure 5. DFMEA Trailer Cart Block Diagram.

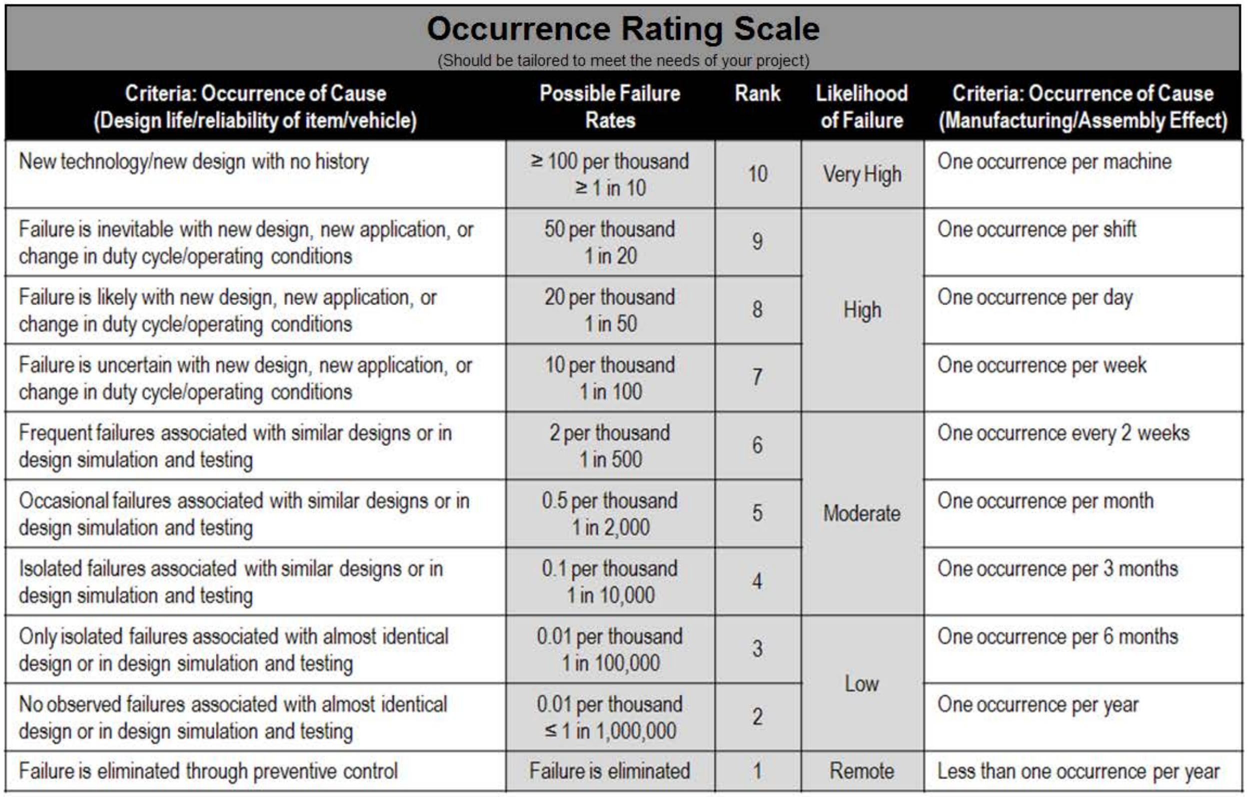
After defining the scope of the DFMEA, the customer was identified. In this case, the customer is the end-user. The end-users are the production workers whose job it is to use the cart to adjust the axle width. They must use the carts multiple times per day to do their jobs. If the cart fails, they are the individuals who experience the most negative outcomes. The production worker is also the most familiar with the operation of the carts, and therefore, is a critical member of the DFMEA team.

During the brainstorming session, the DFMEA team used 5-Why Analyses and Fishbone Diagrams as techniques to investigate the potential root-cause(s) of the failure mode. These techniques are the recommended methods of organizing thoughts during a FMEA brainstorming session as prescribed by XYZ Corporation employee development training classes pertaining to the subject of continuous improvement.

Potential failure mode causes were identified and agreed upon by the DFMEA team. The team also identified any controls that existed in the original design, design process, and manufacturing process that could prevent or detect the specific failure mode. These causes and controls were added to the DFMEA form (Table 6) and assigned Occurrence (D), Severity (S), and Detection (D) ratings based on the guidelines from the AIAG *Potential Failure Mode and Effects Analysis FMEA 4th Ed.* reference manual, shown in Tables 3 thru 5 below.

Table 3

FMEA Occurrence Evaluation Criteria



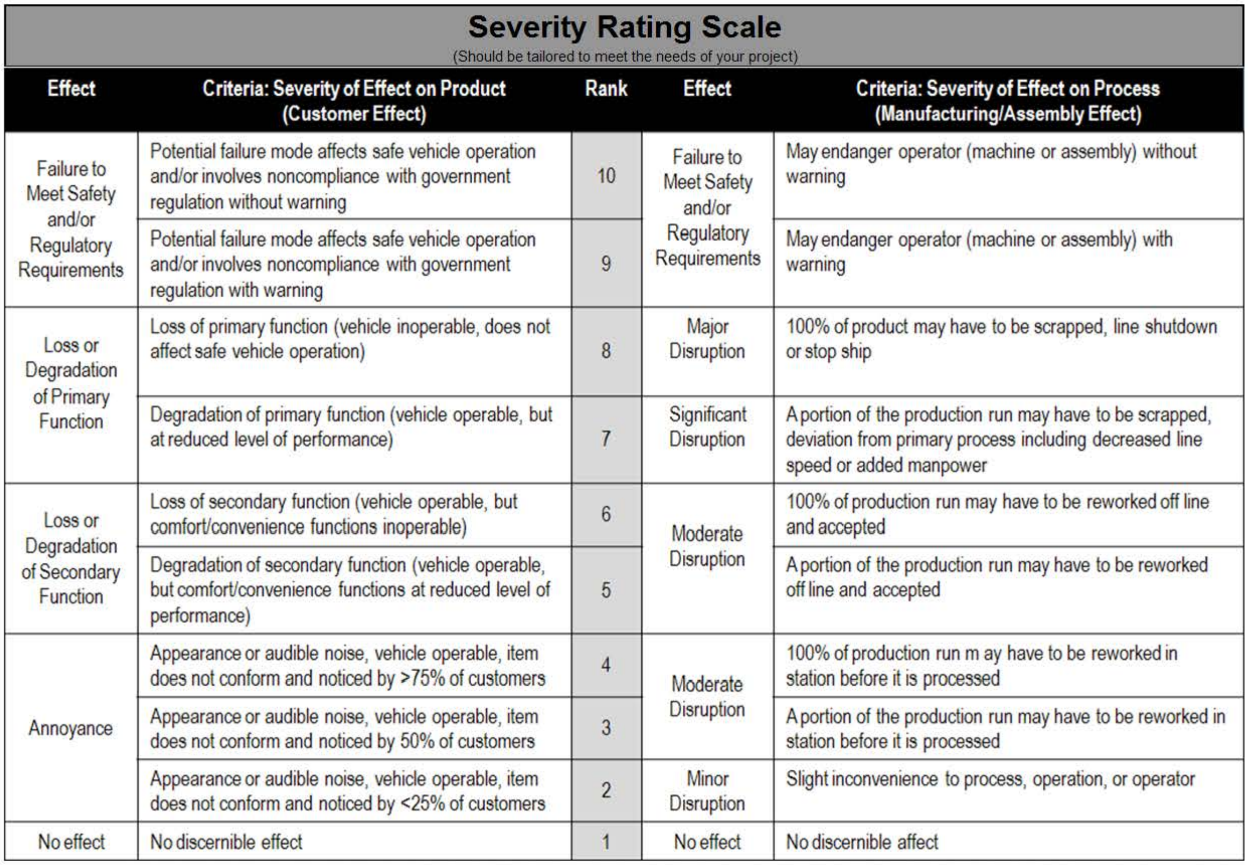
Occurrence Rating Scale

(Should be tailored to meet the needs of your project)

Criteria: Occurrence of Cause (Design life/reliability of item/vehicle)	Possible Failure Rates	Rank	Likelihood of Failure	Criteria: Occurrence of Cause (Manufacturing/Assembly Effect)
New technology/new design with no history	≥ 100 per thousand ≥ 1 in 10	10	Very High	One occurrence per machine
Failure is inevitable with new design, new application, or change in duty cycle/operating conditions	50 per thousand 1 in 20	9	High	One occurrence per shift
Failure is likely with new design, new application, or change in duty cycle/operating conditions	20 per thousand 1 in 50	8		One occurrence per day
Failure is uncertain with new design, new application, or change in duty cycle/operating conditions	10 per thousand 1 in 100	7		One occurrence per week
Frequent failures associated with similar designs or in design simulation and testing	2 per thousand 1 in 500	6	Moderate	One occurrence every 2 weeks
Occasional failures associated with similar designs or in design simulation and testing	0.5 per thousand 1 in 2,000	5		One occurrence per month
Isolated failures associated with similar designs or in design simulation and testing	0.1 per thousand 1 in 10,000	4		One occurrence per 3 months
Only isolated failures associated with almost identical design or in design simulation and testing	0.01 per thousand 1 in 100,000	3	Low	One occurrence per 6 months
No observed failures associated with almost identical design or in design simulation and testing	0.01 per thousand ≤ 1 in 1,000,000	2		One occurrence per year
Failure is eliminated through preventive control	Failure is eliminated	1	Remote	Less than one occurrence per year

Table 4

FMEA Severity Evaluation Criteria



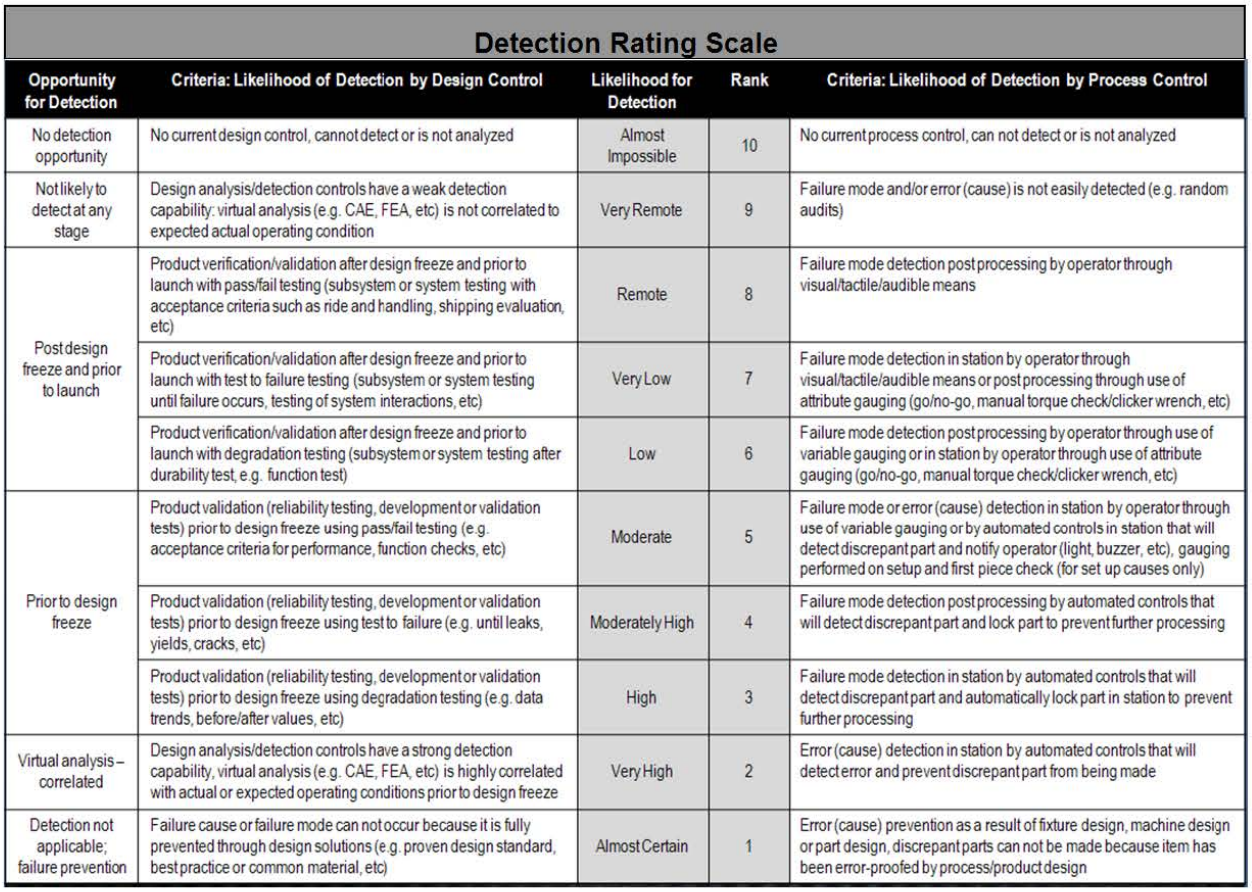
Severity Rating Scale

(Should be tailored to meet the needs of your project)

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank	Effect	Criteria: Severity of Effect on Process (Manufacturing/Assembly Effect)
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning	10	Failure to Meet Safety and/or Regulatory Requirements	May endanger operator (machine or assembly) without warning
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning	9		May endanger operator (machine or assembly) with warning
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation)	8	Major Disruption	100% of product may have to be scrapped, line shutdown or stop ship
	Degradation of primary function (vehicle operable, but at reduced level of performance)	7	Significant Disruption	A portion of the production run may have to be scrapped, deviation from primary process including decreased line speed or added manpower
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort/convenience functions inoperable)	6	Moderate Disruption	100% of production run may have to be reworked off line and accepted
	Degradation of secondary function (vehicle operable, but comfort/convenience functions at reduced level of performance)	5		A portion of the production run may have to be reworked off line and accepted
Annoyance	Appearance or audible noise, vehicle operable, item does not conform and noticed by >75% of customers	4	Moderate Disruption	100% of production run m ay have to be reworked in station before it is processed
	Appearance or audible noise, vehicle operable, item does not conform and noticed by 50% of customers	3		A portion of the production run may have to be reworked in station before it is processed
	Appearance or audible noise, vehicle operable, item does not conform and noticed by <25% of customers	2	Minor Disruption	Slight inconvenience to process, operation, or operator
No effect	No discernible effect	1	No effect	No discernible affect

Table 5

FMEA Detection Rating Evaluation Criteria

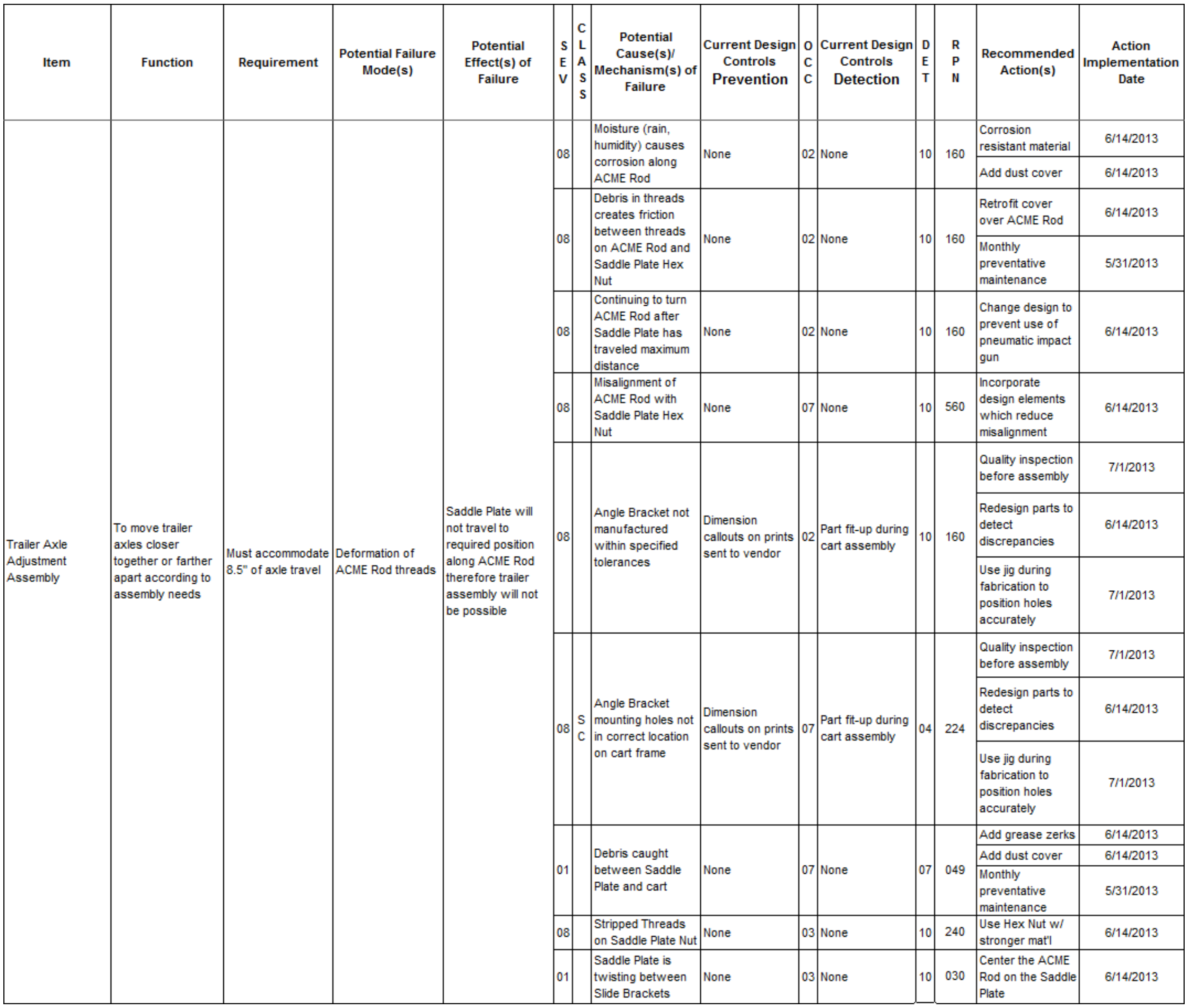


Detection Rating Scale

Opportunity for Detection	Criteria: Likelihood of Detection by Design Control	Likelihood for Detection	Rank	Criteria: Likelihood of Detection by Process Control
No detection opportunity	No current design control, cannot detect or is not analyzed	Almost Impossible	10	No current process control, can not detect or is not analyzed
Not likely to detect at any stage	Design analysis/detection controls have a weak detection capability: virtual analysis (e.g. CAE, FEA, etc) is not correlated to expected actual operating condition	Very Remote	9	Failure mode and/or error (cause) is not easily detected (e.g. random audits)
Post design freeze and prior to launch	Product verification/validation after design freeze and prior to launch with pass/fail testing (subsystem or system testing with acceptance criteria such as ride and handling, shipping evaluation, etc)	Remote	8	Failure mode detection post processing by operator through visual/tactile/audible means
	Product verification/validation after design freeze and prior to launch with test to failure testing (subsystem or system testing until failure occurs, testing of system interactions, etc)	Very Low	7	Failure mode detection in station by operator through visual/tactile/audible means or post processing through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc)
	Product verification/validation after design freeze and prior to launch with degradation testing (subsystem or system testing after durability test, e.g. function test)	Low	6	Failure mode detection post processing by operator through use of variable gauging or in station by operator through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc)
Prior to design freeze	Product validation (reliability testing, development or validation tests) prior to design freeze using pass/fail testing (e.g. acceptance criteria for performance, function checks, etc)	Moderate	5	Failure mode or error (cause) detection in station by operator through use of variable gauging or by automated controls in station that will detect discrepant part and notify operator (light, buzzer, etc), gauging performed on setup and first piece check (for set up causes only)
	Product validation (reliability testing, development or validation tests) prior to design freeze using test to failure (e.g. until leaks, yields, cracks, etc)	Moderately High	4	Failure mode detection post processing by automated controls that will detect discrepant part and lock part to prevent further processing
	Product validation (reliability testing, development or validation tests) prior to design freeze using degradation testing (e.g. data trends, before/after values, etc)	High	3	Failure mode detection in station by automated controls that will detect discrepant part and automatically lock part in station to prevent further processing
Virtual analysis – correlated	Design analysis/detection controls have a strong detection capability, virtual analysis (e.g. CAE, FEA, etc) is highly correlated with actual or expected operating conditions prior to design freeze	Very High	2	Error (cause) detection in station by automated controls that will detect error and prevent discrepant part from being made
Detection not applicable; failure prevention	Failure cause or failure mode can not occur because it is fully prevented through design solutions (e.g. proven design standard, best practice or common material, etc)	Almost Certain	1	Error (cause) prevention as a result of fixture design, machine design or part design, discrepant parts can not be made because item has been error-proofed by process/product design

Table 6

DFMEA Form with Initial RPN Values



Item	Function	Requirement	Potential Failure Mode(s)	Potential Effect(s) of Failure	SEV	CLASS	Potential Cause(s)/ Mechanism(s) of Failure	Current Design Controls Prevention	OCC	Current Design Controls Detection	DET	RPN	Recommended Action(s)	Action Implementation Date
Trailer Axle Adjustment Assembly	To move trailer axles closer together or farther apart according to assembly needs	Must accommodate 8.5" of axle travel	Deformation of ACME Rod threads	Saddle Plate will not travel to required position along ACME Rod therefore trailer assembly will not be possible	08		Moisture (rain, humidity) causes corrosion along ACME Rod	None	02	None	10	160	Corrosion resistant material	6/14/2013
													Add dust cover	6/14/2013
					08		Debris in threads creates friction between threads on ACME Rod and Saddle Plate Hex Nut	None	02	None	10	160	Retrofit cover over ACME Rod	6/14/2013
													Monthly preventative maintenance	5/31/2013
					08		Continuing to turn ACME Rod after Saddle Plate has traveled maximum distance	None	02	None	10	160	Change design to prevent use of pneumatic impact gun	6/14/2013
					08		Misalignment of ACME Rod with Saddle Plate Hex Nut	None	07	None	10	560	Incorporate design elements which reduce misalignment	6/14/2013
					08		Angle Bracket not manufactured within specified tolerances	Dimension callouts on prints sent to vendor	02	Part fit-up during cart assembly	10	160	Quality inspection before assembly	7/1/2013
													Redesign parts to detect discrepancies	6/14/2013
													Use jig during fabrication to position holes accurately	7/1/2013
					08	SC	Angle Bracket mounting holes not in correct location on cart frame	Dimension callouts on prints sent to vendor	07	Part fit-up during cart assembly	04	224	Quality inspection before assembly	7/1/2013
													Redesign parts to detect discrepancies	6/14/2013
													Use jig during fabrication to position holes accurately	7/1/2013
					01		Debris caught between Saddle Plate and cart	None	07	None	07	049	Add grease zerks	6/14/2013
													Add dust cover	6/14/2013
													Monthly preventative maintenance	5/31/2013
					08		Stripped Threads on Saddle Plate Nut	None	03	None	10	240	Use Hex Nut w/ stronger mat'l	6/14/2013
					01		Saddle Plate is twisting between Slide Brackets	None	03	None	10	030	Center the ACME Rod on the Saddle Plate	6/14/2013

Once the causes and controls were entered into the DFMEA form and assigned numerical ratings, the Risk Priority Number for each cause was calculated using this formula:

Severity (S) x Occurrence (O) x Detection (D) = Risk Priority Number (RPN)

The threshold RPN number for designs already in production, as is the case with these trailer carts, is 40. This was a number predetermined by XYZ Corporation. As shown in the above table, all causes have an RPN above the threshold limit of 40, and therefore, must be addressed.

The multidisciplinary DFMEA team used the experience and expertise of the individual team members to develop recommended action plans with the intent of lowering RPN values to 40 or below.

Limitations

Continued use of the trailer carts irrespective of safety could have resulted in a lower number of repairs than should have actually been recorded. Proper use of the trailer carts was not monitored. The data collection method did not differentiate between failures caused under normal working conditions and failures caused as a result of negligence.

Chapter IV: Results

XYZ Corporation currently uses in-house designers and fabricators to develop special assembly tooling. The existence of this tooling is critical to the day-to-day operations of manufacturing XYZ Corporation's products. The special assembly tooling provided must meet specific requirements of safety, ergonomics, reliability, maintainability, durability, usability and cost. However, XYZ Corporation's Tool Department does not currently have a systematic approach to developing special assembly tools that consistently meet the above criteria. DFMEA is a systematic method for the design of parts, assemblies and sub-assemblies. The purpose of this study is to determine whether DFMEA is an effective method for improving the design of special assembly tooling at XYZ Corporation.

An existing special assembly tool was chosen as the subject for this study. The trailer assembly cart is a type of special assembly tooling at XYZ Corporation that adequately represents the relative complexity of all special tooling developed by XYZ Corporation's tooling department. These carts were also chosen because of the frequency of repairs that they required. Assemblers had to frequently reject these carts because they would become damage to the point where they could no long operate. To begin the study, information pertaining to the rejections and repairs was collected by Repairs Logs and analyzed.

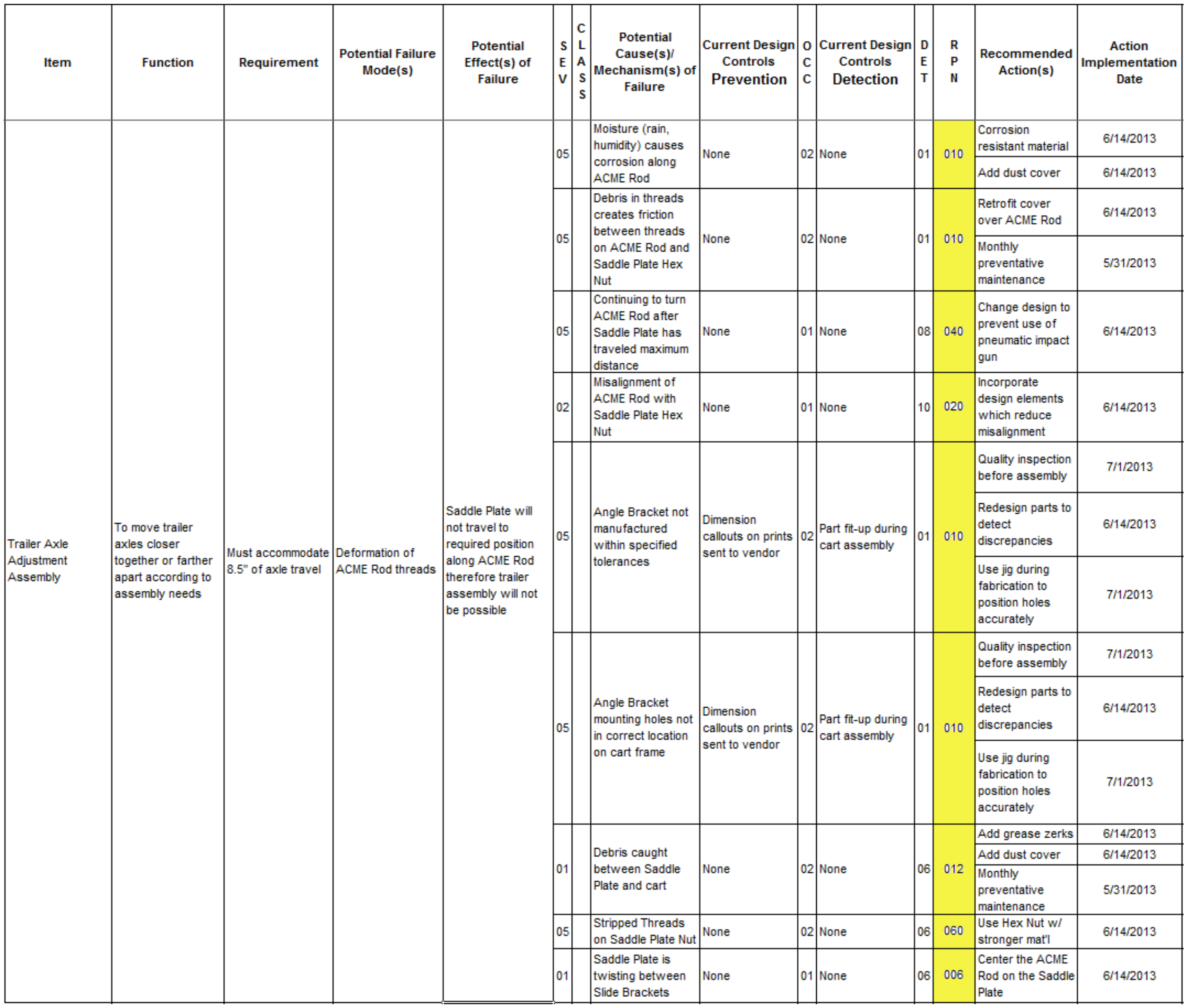
The methodology of the study was to use DFMEA to determine whether or not it is an effective approach to improving the design of the existing special assembly tool. First, the DFMEA team was assembled. A brainstorming session was conducted to determine possible causes of the major failure mode that was identified from the data collected in the Repair Logs.

The DFMEA form was completed with RPN values for each cause of failure according to the *Potential Failure Mode and Effects Analysis FMEA 4th Ed.* reference manual. The recommended actions for each cause of failure were implemented. This section of the report shows the results of the implementation of the recommended actions listed on the DFMEA form and impact those actions had on the RPN values for each cause of failure.

The data collected from the Repair Logs showed that the main reason for the rejection of trailer carts was due to the threads stripping on the ACME rod. The DFMEA focused on this failure mode to determine some of its potential causes. The DFMEA team collectively determined the potential causes and provided recommended actions to prevent and detect those causes. New values were assigned to Severity (S), Occurrence (O), and Detection (D) based on the collective knowledge and experience of the DFMEA team. Table 7 below highlights the new RPN values for the causes of failure.

Table 7

DFMEA Form with New RPN Values



Item	Function	Requirement	Potential Failure Mode(s)	Potential Effect(s) of Failure	SEV	CLASS	Potential Cause(s)/ Mechanism(s) of Failure	Current Design Controls Prevention	OCC	Current Design Controls Detection	DET	RPN	Recommended Action(s)	Action Implementation Date
Trailer Axle Adjustment Assembly	To move trailer axles closer together or farther apart according to assembly needs	Must accommodate 8.5" of axle travel	Deformation of ACME Rod threads	Saddle Plate will not travel to required position along ACME Rod therefore trailer assembly will not be possible	05		Moisture (rain, humidity) causes corrosion along ACME Rod	None	02	None	01	010	Corrosion resistant material Add dust cover	6/14/2013 6/14/2013
					05		Debris in threads creates friction between threads on ACME Rod and Saddle Plate Hex Nut	None	02	None	01	010	Retrofit cover over ACME Rod Monthly preventative maintenance	6/14/2013 5/31/2013
					05		Continuing to turn ACME Rod after Saddle Plate has traveled maximum distance	None	01	None	08	040	Change design to prevent use of pneumatic impact gun	6/14/2013
					02		Misalignment of ACME Rod with Saddle Plate Hex Nut	None	01	None	10	020	Incorporate design elements which reduce misalignment	6/14/2013
					05		Angle Bracket not manufactured within specified tolerances	Dimension callouts on prints sent to vendor	02	Part fit-up during cart assembly	01	010	Quality inspection before assembly Redesign parts to detect discrepancies Use jig during fabrication to position holes accurately	7/1/2013 6/14/2013 7/1/2013
					05		Angle Bracket mounting holes not in correct location on cart frame	Dimension callouts on prints sent to vendor	02	Part fit-up during cart assembly	01	010	Quality inspection before assembly Redesign parts to detect discrepancies Use jig during fabrication to position holes accurately	7/1/2013 6/14/2013 7/1/2013
					01		Debris caught between Saddle Plate and cart	None	02	None	06	012	Add grease zerks Add dust cover Monthly preventative maintenance	6/14/2013 6/14/2013 5/31/2013
					05		Stripped Threads on Saddle Plate Nut	None	02	None	06	060	Use Hex Nut w/ stronger mat'l	6/14/2013
					01		Saddle Plate is twisting between Slide Brackets	None	01	None	06	006	Center the ACME Rod on the Saddle Plate	6/14/2013

DFMEA Design Modifications

As shown in Table 7 above, the new RPN values for the causes of failure have been significantly reduced by the implementation of the recommended actions. All RPN values except for one have been reduced to 40 and below. The acceptable RPN threshold value at XYZ Corporation for existing designs already in production is 40. The RPN value of 60 for the Stripped Threads on Saddle Plate Nut cause of failure could probably be lowered due a design change that occurred that was not originally part of the DFMEA recommended actions, but was determined during fabrication to be an important modification to improve the design of the cart. This change is shown below in Figure 6, labeled as Elongated Hex Nut, and is discussed in further detail below along all the other design changes that occurred from the DFMEA.

The implemented DFMEA design changes are highlighted in Figures 6 and 7 below. The dust cover was added to keep debris and moisture from entering the threads on the ACME rod. This prevents binding between the rod and hex nut, which had inhibited the linear travel of saddle plate, thus requiring more force to operate the cart and thereby stripping the threads. The material of the ACME rod was also changed from mild steel to stainless steel to reduce corrosion of the rod. The dust cover by itself will not prevent all moisture from making contact with the ACME rod. The change from mild to stainless steel combined with the new cover will provide enough protection from corrosion to mitigate the problem of binding between the rod and hex nut. Furthermore, the new monthly preventative maintenance schedule of the carts will keep the ACME rod lubricated and clear of any accumulated debris. The ACME rods will also be inspected for damage and replaced or repaired as required.

The problem of overturning the ACME rod with the use of an impact gun was eliminated by changing the cart operation interface from the hex nut configuration to a removable crank-handle. The crank-handle is attached by sliding the crank onto a square rod. The square rod prevents the use of an impact gun because the assemblers are not provided with a square socket to mate with the square rod. The manually-operated ratchet-style crank allows the operators to adjust the saddle in both directions with sufficient torque to move the axles, but not enough to strip the stronger stainless steel ACME rod threads.

In order to keep the ACME rod and saddle plate hex nut aligned, a locating notch was incorporated into the design of the saddle plate. The notch was provided to eliminate misalignment during fabrication of the trailer cart. With the notch in the saddle plate, the welder needs only to fit the hex nut into the notch and weld it to the saddle plate. The notch in the saddle plate has the added benefit of bringing the ACME rod closer to the center of the saddle plate, which improves alignment and decreases side-to-side twisting of the saddle plate. Furthermore, the saddle plate profile is cut on a water-jet machine, which is capable of cutting features within ±.005”. This is an improvement over the ±.060” previously allowed, and will aid in improving the alignment between the ACME rod and saddle plate hex nut.

The saddle plate hex nut was also modified. The original nut was replaced with an elongated hex nut and the material has been changed from mild to stainless steel to provide more strength against stripping. The longer hex nut will keep more threads of the ACME rod engaged with the hex nut. More thread engagement between the ACME rod and hex nut means less side-to-side twisting of the saddle plate, and therefore; less friction between the threads of the ACME rod and hex nut. Less friction between the ACME rod and hex nut reduces the possibility of the ACME rod threads stripping.

The next design change that was made incorporated grease fittings into the bottom of the cart structure as shown in Figure 7. The dust cover design modification will keep most of the debris from settling on the moving surfaces of the trailer cart axle adjustment components. However, not all dust and moisture can be prevented from entering into the operating components. By adding the grease fittings under the saddle plate, the surface of the trailer structure and saddle plate can be lubricated during the monthly preventative maintenance. This added feature mitigates the friction between these two surfaces caused by debris and protects them from corrosion.

The final design change was made on the angle bracket. Originally, the angle bracket had two screws per bracket threaded into the cart structure. These screws would eventually become loose and strip-out the threads in the cart. To repair this, the threaded holes in the cart had to be plug-welded and re-tapped. This was a time-consuming and imprecise process. The potential for the threads in the cart to be re-tapped in the wrong location and create misalignment between the ACME rod and hex nut was high. The new angle bracket design has a longer flange where two screws were added and provide a tighter connection between the angle bracket and the cart structure. This design change reduces the possibility of the screws stripping out of the threads in the cart, therefore; decreasing misalignment and repairs.

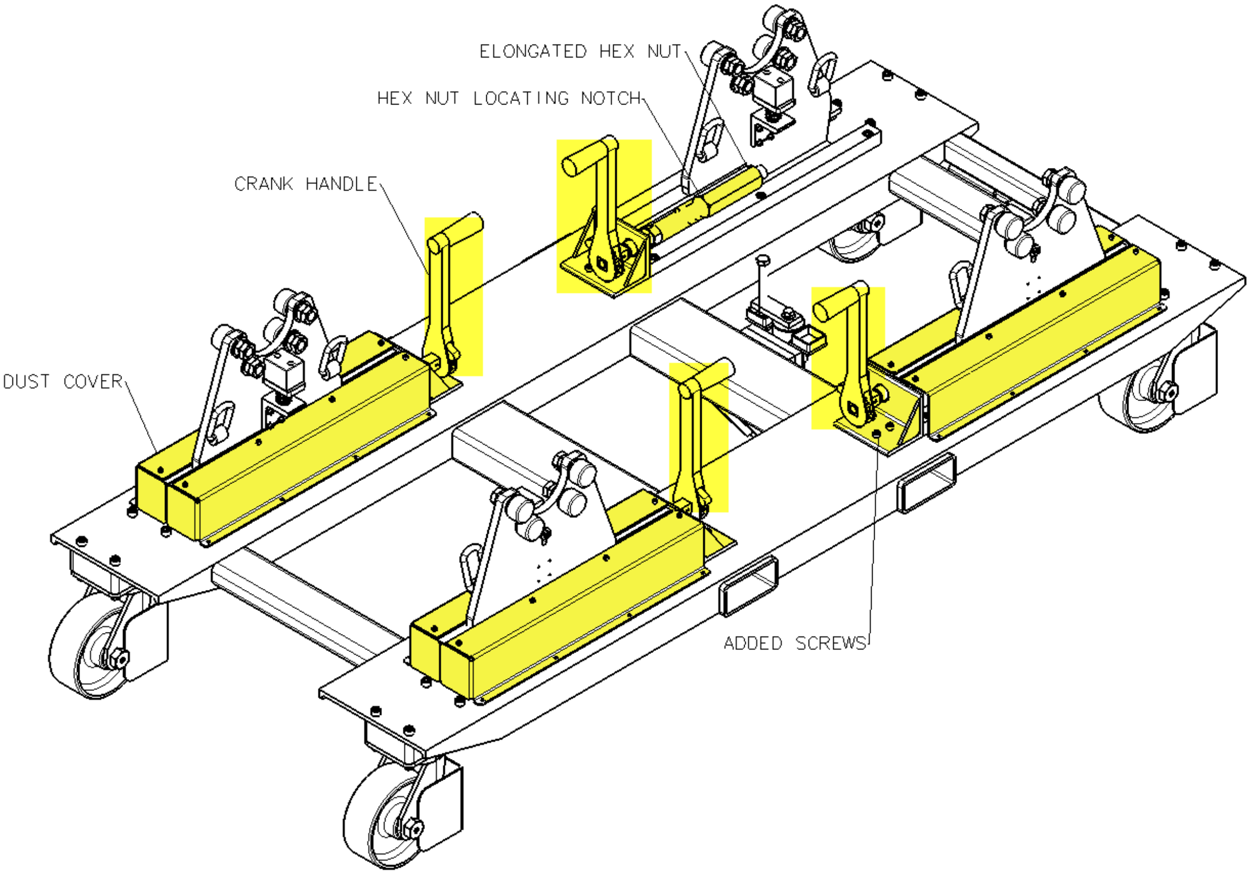


Figure 6. Top view of trailer cart with DFMEA recommended design changes.

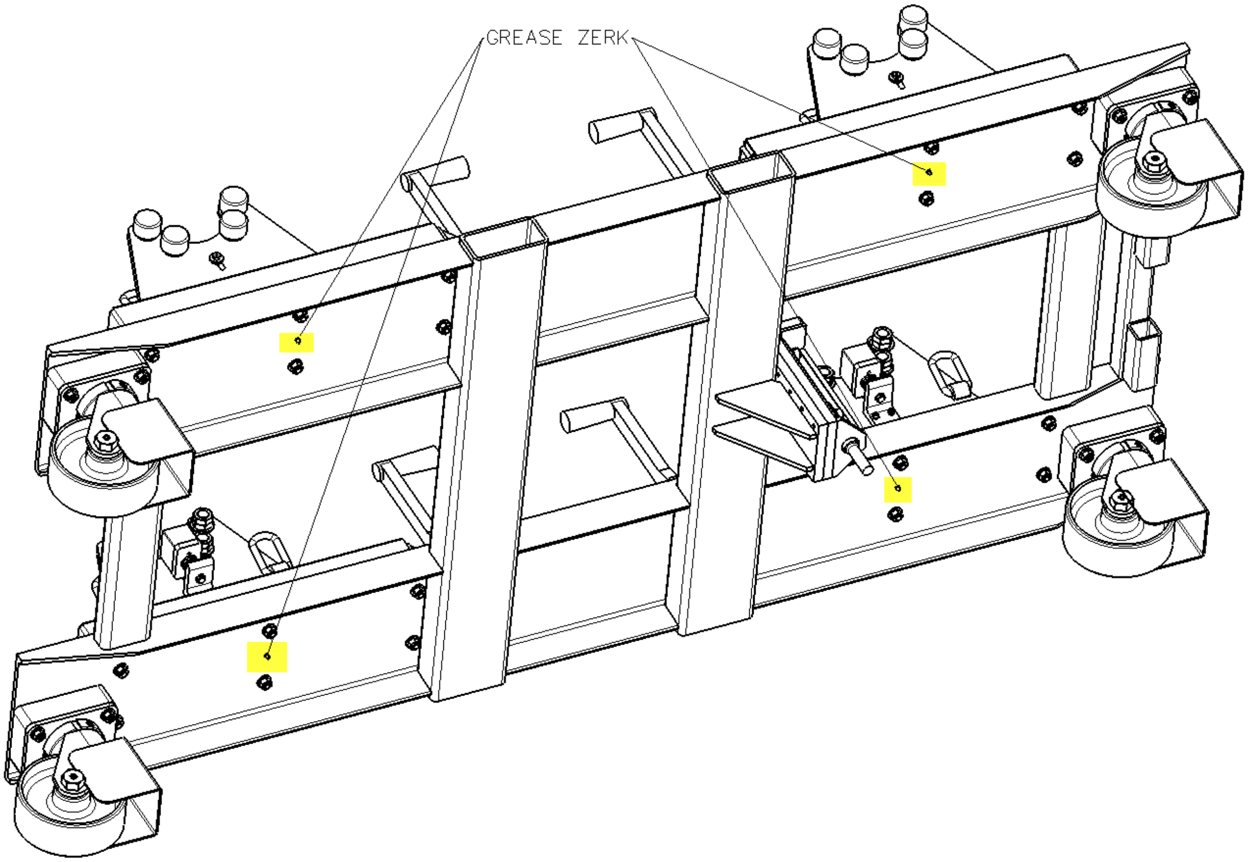


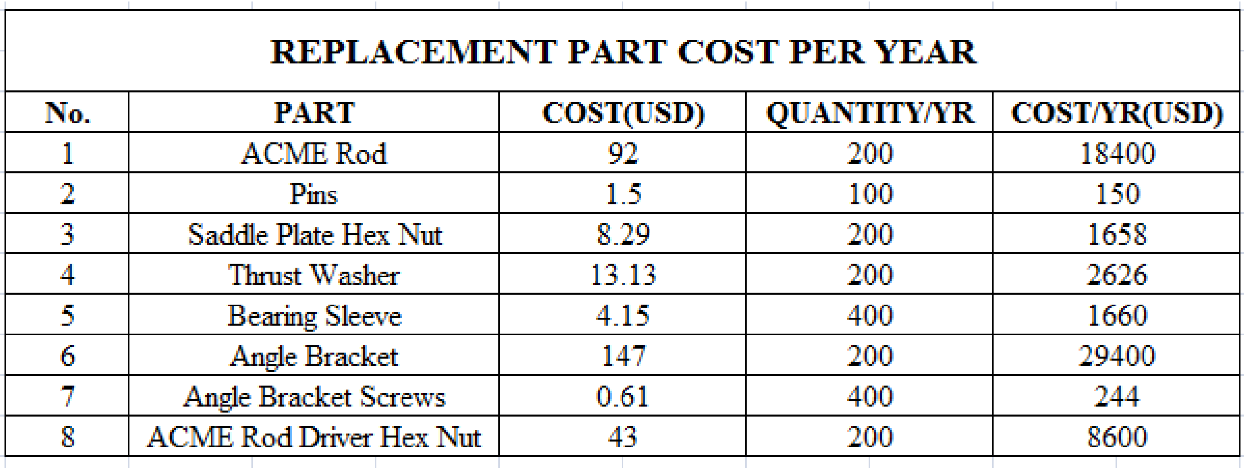
Figure 7. Bottom view of trailer cart with DFMEA recommended design changes.

Item Analysis

In addition to the reasons for the rejection of the carts, the Repair Logs collected data on the parts that needed to be replaced, their quantities and the time required to replace them. The data was then used to get a yearly average quantity and cost, as shown in Tables 8 and 9 below.

Table 8

List of Parts with Cost Per Part, Quantity Replaced Per Year and Cost Per Year to Replace those Parts

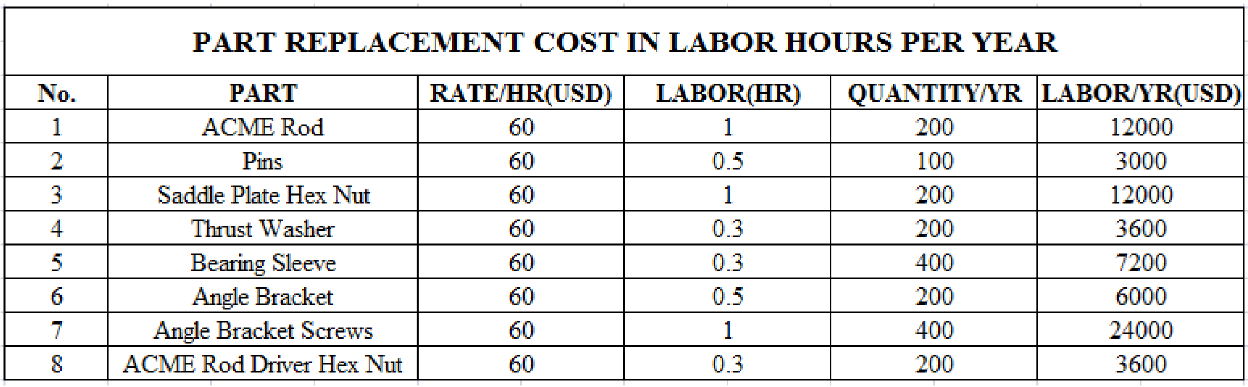


REPLACEMENT PART COST PER YEAR

No.	PART	COST(USD)	QUANTITY/YR	COST/YR(USD)
1	ACME Rod	92	200	18400
2	Pins	1.5	100	150
3	Saddle Plate Hex Nut	8.29	200	1658
4	Thrust Washer	13.13	200	2626
5	Bearing Sleeve	4.15	400	1660
6	Angle Bracket	147	200	29400
7	Angle Bracket Screws	0.61	400	244
8	ACME Rod Driver Hex Nut	43	200	8600

Table 9

List of Parts with Labor Rate, Hours Needed to Replace Parts, Quantity of Parts Per Year and Labor Cost to Replace those Parts Per Year

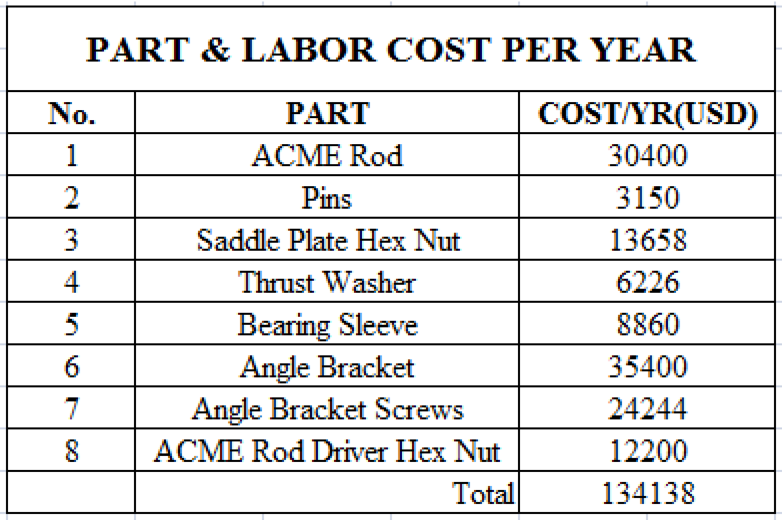


PART REPLACEMENT COST IN LABOR HOURS PER YEAR

No.	PART	RATE/HR(USD)	LABOR(HR)	QUANTITY/YR	LABOR/YR(USD)
1	ACME Rod	60	1	200	12000
2	Pins	60	0.5	100	3000
3	Saddle Plate Hex Nut	60	1	200	12000
4	Thrust Washer	60	0.3	200	3600
5	Bearing Sleeve	60	0.3	400	7200
6	Angle Bracket	60	0.5	200	6000
7	Angle Bracket Screws	60	1	400	24000
8	ACME Rod Driver Hex Nut	60	0.3	200	3600

Table 10

List of Parts with the Total Cost of Parts and Labor Per Year



PART & LABOR COST PER YEAR		
No.	**PART**	**COST/YR(USD)**
1	ACME Rod	30400
2	Pins	3150
3	Saddle Plate Hex Nut	13658
4	Thrust Washer	6226
5	Bearing Sleeve	8860
6	Angle Bracket	35400
7	Angle Bracket Screws	24244
8	ACME Rod Driver Hex Nut	12200
	Total	134138

As shown in Table 10 above, the improvements from the DFMEA have the potential to save the company up to $134,138 a year. Factored into this number is the elimination of all repairs and part replacements. Ideally, with the DFMEA design changes made to the cart and the implementation of preventative maintenance, which includes lubricating all moving parts and inspecting their condition, and the addition of assembly and fabrication jigs, all costs previously associated with repairing the carts could be eliminated.

Chapter V: Discussion

The purpose of this study was to determine if DFMEA could be used as an effective method for improving the design of special assembly tooling. The subject of the study was an existing special assembly tool used to transport a 5 ton military trailer. The trailer cart has an integrated system for assemblers to use to adjust the spacing between the front and rear axles of the trailer. This system experienced frequent failures and was commonly rejected by assembly for repairs. Repair data was collected to determine the nature of the damage to the carts and the reasons for rejection. This information led to the identification of a failure mode responsible for almost 90% of the rejections. The DFMEA team used their collective knowledge and experience to uncover potential causes of this failure and assigned RPN values to them. Recommended actions were given for each cause and then implemented on the design of the cart. The results of the implemented DFMEA design changes and other recommended actions have reduced cart rejections 100% and as the potential to save XYZ Corporation $134,138 annually.

Discussion

DFMEA and PFMEA are recognized and accepted by the industry to be a proven method under the continuous improvement paradigm for improving product designs and assembly processes. Studies have been conducted on FMEAs to determine the effectiveness of the protocols outlined in FMEAs on a variety of product designs and processes. The design of special assembly tooling, however, has not been tested against the DFMEA method.

XYZ Corporation uses DFMEA and PFMEA in the development of products it sells to its external customers. The tooling department within XYZ Corporation has the characteristics of a separate company that operates within the organization. For this reason, it is not governed by the same standards and procedures as other departments. However, within the tooling department exist many of the same functional requirements as the rest of the company, such as purchasing, design, fabrication, and assembly. The main difference is that the tooling department does not share the same standards and procedures as the rest of the company.

The tooling department's external customer is the operations department of XYZ Corporation. It provides tooling solutions for issues related to safety, ergonomics, quality, process improvement, assembly, and manufacturing to the operations department. Therefore, tooling is a critical part in the manufacture of the end product that is eventually used by the Company's external customer.

A discrepancy exists between the tooling department and all other departments within operations. The discrepancy is that the emphasis on continuous improvement is not placed on tooling to the same degree as it is on other departments in operations. Manufacturing, quality, safety and assembly all have continuous improvement based procedures, methods, and efforts.

Many of the efforts to improve these departments involve the use of new tooling provided by the tooling department. It is in the best interest of the organization to extend the use of continuous improvement methods such as DFMEA and PFMEA in the development of these tools.

Conclusions

This paper has shown that it is not only possible, but also profitable for companies to not overlook the importance of special assembly tools. XYZ Corporation has the potential to cut more than $134,000 dollars annually just by implementing the design changes and other recommendations from the DFMEA of just one special assembly tool. It also emphasizes the fact that FMEA and other improvement methods can and should be part of continuous improvement efforts in departments other than just the traditional ones of product design and manufacturing engineering.

DFMEA is a powerful continuous improvement tool. Its use extends beyond just the identification and ranking of failure modes and causes. Once a FMEA has been conducted, it can be used again as a reference for future design improvements or new product designs. It can be used as a way to document lessons-learned on previous designs, so the same mistakes are not repeated and carried over into new products.

Recommendations

Further study could be conducted on the role of tooling in the continuous improvement efforts of manufacturing companies.

References

Chrysler LLC, Ford Motor Company, General Motors Corporation. (2008). *Potential failure mode and effects analysis FMEA* (4th ed.). Retrieved from: www.aiag.org

Arabzad, S.M., Razmi, J., & Ghorbani, M. (2011). Classify purchasing items based on risk and profitability attributes; using MCDM and FMEA techniques. *Research Journal of International Studies, 21*, 80-85.

Cotnareanu, T. (1999). Old tools--new uses: Equipment FMEA. *Quality Progress, 32*(12), 48.

Hounshell, D.A. (1984). *From the American system to mass production*, *1800-1932*. Baltimore, MD: Johns Hopkins.

Keskin, G., & Özkan, C. (2009). An alternative evaluation of FMEA: Fuzzy ART algorithm. *Quality & Reliability Engineering International, 25*(6), 647-661. doi: 10.1002/qre.984

Kumar, A., Poonia, M.P., Pandel, U., & Jethoo, A.S. (2011). FMEA: Methodology, design and implementation in a foundry. *International Journal of Engineering Science & Technology, 3*(6), 5288-5297.

Ling, J., Hsieh, P., & Cowing, T. (2005). Reliability engineering practice in the light duty dodge ram truck chassis program. *Quality & Reliability Engineering International, 21*(1), 1-11. doi: 10.1002/qre.639

McCain, C. (2006). Using an FMEA in a service setting. *Quality Progress, 39*(9), 24-29.

Namdari, M., Rafiee, S., & Jafari, A. (2011). Using the FMEA method to optimize fuel consumption in tillage by moldboard plow. *International Journal of Applied Engineering Research (0976-4259), 1*(4), 734-742.

Nee, J.G. (2010). *Fundamentals of tool design* (6th ed.). *Dearborn, MI:* Society of Manufacturing Engineers.

Niezgoda, S.L., & Johnson, P.A. (2007). Case study in cost-based risk assessment for selecting a stream restoration design method for a channel relocation project. *ASCE, Journal of Hydraulic Engineering*, 133(5):468-478.

Putcha, C.S., Kalia, P., Pizzano, F., Hoskins, G., Newton, C., & Kamdar, K.J. (2008). A case study on FMEA applications to system reliability studies. *International Journal of Reliability, Quality & Safety Engineering, 15*(2), 159-166.

Sofyalioğlu, Ç., & Öztürk, Ş. (2012). Application of grey relational analysis with fuzzy AHP to FMEA method. *Dogus University Journal, 13*(1), 114-130.

Vladimir Popović, Branko Vasić, & Milo Petrović. (2010). The possibility for FMEA method improvement and its implementation into bus life cycle. *Strojniski Vestnik / Journal of Mechanical Engineering, 56*(3), 179-185.

Welborn, C. (2007). Using FMEA to assess outsourcing risk. *Quality Progress, 40*(8), 17-21.