Improvement of accuracy level using process failure mode and effect analysis and control plan techniques for automotive fender shield assembly

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This paper reports Process Failure Mode and Effect Analysis (PFMEA) and control plan (CP) techniques used as preventive tools to ensure products being produced are of high quality. Data analysis based on parts’ coordinate in X, Y and Z positions are performed to determine the root cause of failures. Data in prototype (P0 and P1) stage are used to prove effectiveness of PFMEA and CP techniques prior to and after both techniques have been applied in the product development process for Front Fender Shield Assembly Left Hand. Integration between PFMEA and CP and minimum target of accuracy level (85%) has been successfully achieved.

Keywords: Automotive industry, Control plan, PFMEA, Quality level

Introduction

A company’s performance does not depend upon its capabilities alone, but also on increased outsourcing, supply base reduction, and consolidation1,2. Customer tolerance for properties that do not live up to the expected level is very small in the future3. Foresight and imagination are needed to predict potential problems and to devise corrective actions that prevent their occurrence or at least minimize their effects4. Several empirical studies have explored relationship between quality management practices and conformance quality. Flynn et al5 explored quality management practices of high-, medium-, or low-performing plants based on self-reported yield rates, and showed that high and low performers had high usage levels, while medium performers had lower usage levels of these practices.

A survey of Ohio plant managers based on the Malcolm Baldrige National Quality Award (MBNQAC) found that process quality, human resource management, and information and analysis were positively correlated with self-reported plant performance6. Ahire & Dreyfus7 explored relationships among design management, product design performance, quality training, process quality management, and internal and external quality. In another study8, greater customer focus, supplier quality management, and employee empowerment were shown related to higher perceived product quality. Adam9 did a cross-industry survey of quality and productivity management based on MBNQAC, and found that many quality practices have little practical impact on performance. Grandzol & Gershon10 studied quality management used by US defense contractors from aerospace, tooling and engineering industries. Dow et al11 measured relationship between nine quality management practices, of which, only three (workforce commitment, shared vision and customer focus) showed a significant statistical relationship with quality performance. Forker12 expanded the realm of quality management research into a supply chain context.

This study presents the use of process failure mode and effect analysis and control plan techniques for automotive fender shield assembly in improving accuracy level.

Methodology

Process development of Front Fender Shield Assembly Left Hand (FFSALH) starts with the preparation of bill of material (BOM) list (Fig. 1). BOM list is to be used as reference in determining which processes and parts are required during the development stage. Information from BOM list is used as input for Process Failure Mode and Effect Analysis (PFMEA) and Control Plan (CP) techniques, as these techniques themselves are also used as tools to control the manufacturing process. Information in BOM list,
extracted by Cross Functional Team (CFT), comprising persons from various departments (Engineering, Purchasing, Product Development and Production) is used to conduct feasibility study to analyze the criticality, significantly and reliability of the parts produced.

There are 10 child parts involved to produce one complete set of FFSALH, whereby stamping process is required to manufacture all the child parts (Table 1). Since the child parts are assembled using spot welding process (SWP), therefore, both stamping and SWP are required to be controlled, using PFMEA and CP techniques, by predicting the possibility of failures happening during these processes.

Part name, part number, die change letter and supplier data need to be updated to ensure that there is no non-conformance issue, such as fabricating tooling for child parts based on the old or expired information taken from drawings and computer aided data (CAD). Therefore, this is the earliest step that needs to be taken to ensure the supplier would only produce right parts at the right time. Process flow chart for FFSALH (Fig. 2) is shown. One of the limitations of the study is that since the output data of PFMEA is taken as input for CP, the chance of errors being carried along may lead to the lack of credibility of quality of the product and should be considered in future study.

In the study of PFMEA, risk priority number (RPN) is the product of severity ($S$), occurrence ($O$), and detection ($D$) rankings.

$$RPN = S \times O \times D$$

$S$ is the rank associated with most serious effect for a given failure mode. $S$ is a relative ranking within the scope of individual PFMEA. If the customer affected by a failure mode is manufacturing or assembly plant or product user, assessing $S$ may lie outside the immediate process engineer’s or team’s field of experience or knowledge. In these cases, PFMEA designer, design engineer, and/or subsequent manufacturing or assembly plant process engineer, should be consulted. $O$ is likelihood that a specific cause or mechanism of failure will occur. $D$ is the rank associated with the best detection control listed in the process control column. $D$ is a relative ranking, within the scope of individual PFMEA. In order to achieve a lower ranking, generally the planned process control has to be improved.

**Results and Discussion**

**PFMEA’s Spot Welding Process**

For SWP, there are four potential failure modes (wrong spot location, spot missing, no fusion and spot hole). Highest severity was observed between no fusion and spot hole. This causes vehicle/item inoperable and loss of primary function or full product may have to be scrapped, or vehicle/item reworked in Rework Department with a rework time $>1$ h. Based on severity ranking, table for both processes was determined at 8 (Table 2) as a significant characteristic (SC). Between no fusion and spot hole, highest occurrence is selected, which in this case is not enough current at 2. Ranking 2 is identified based on occurrence rating table, where probability of failure is remote at 0.1 per thousand pieces.

Based on current process control, there are two techniques (prevention and detection). For prevention
Table 1 — Bill of material (BOM) list for front fender shield assembly left hand

<table>
<thead>
<tr>
<th>No</th>
<th>Drawing No</th>
<th>Part Name</th>
<th>Qty</th>
<th>Die CL</th>
<th>Supplier Data</th>
<th>Die Maker</th>
<th>Stamping Vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PW867039X1</td>
<td>FR FNDR SHIELD ASSY LH</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.1</td>
<td>PW867043</td>
<td>Frame Assy Upr Otr Lh</td>
<td>1</td>
<td>C</td>
<td>C (P0)</td>
<td>Customer</td>
<td>Customer</td>
</tr>
<tr>
<td>1.2</td>
<td>PW867039</td>
<td>Shild Assy Fr Fndr Lh</td>
<td>1</td>
<td>D</td>
<td>D (P0)</td>
<td>Customer</td>
<td>Customer</td>
</tr>
<tr>
<td>1.3</td>
<td>PW869522</td>
<td>R/F Eng Mt Rr</td>
<td>1</td>
<td>A</td>
<td>A (P1)</td>
<td>Asastek</td>
<td>Asastek</td>
</tr>
<tr>
<td>1.4</td>
<td>PW867465</td>
<td>R/F Assy Eng Mt Frt</td>
<td>1</td>
<td>B</td>
<td>B (P1)</td>
<td>Brimal</td>
<td>Brimal</td>
</tr>
<tr>
<td>1.5</td>
<td>PW867045</td>
<td>Frm Assy Upr Inr Lh</td>
<td>1</td>
<td>F</td>
<td>F (P1)</td>
<td>Customer</td>
<td>Customer</td>
</tr>
<tr>
<td>1.6</td>
<td>PW869064</td>
<td>Brkt Assy Fndr Upr Lh</td>
<td>1</td>
<td>---</td>
<td>--- (P0)</td>
<td>Asastek</td>
<td>Asastek</td>
</tr>
<tr>
<td>1.7</td>
<td>PW868125</td>
<td>Clsr Frame Upr Lh</td>
<td>1</td>
<td>A</td>
<td>A (P0)</td>
<td>Asastek</td>
<td>Asastek</td>
</tr>
<tr>
<td>1.8</td>
<td>PW867035</td>
<td>Pnl Sprg Hse Fr Lh</td>
<td>1</td>
<td>G</td>
<td>G (PP)</td>
<td>Customer</td>
<td>Customer</td>
</tr>
<tr>
<td>1.9</td>
<td>PW867037</td>
<td>Brkt Sprg Hse Fr Lh</td>
<td>1</td>
<td>D</td>
<td>D (P1)</td>
<td>HMC</td>
<td>Autokeen</td>
</tr>
<tr>
<td>1.10</td>
<td>PW867459</td>
<td>Brkt Fuel Canister</td>
<td>1</td>
<td>D</td>
<td>D (PP)</td>
<td>HMC</td>
<td>Autokeen</td>
</tr>
</tbody>
</table>

Fig. 2 — Process flow chart for FFSALH
technique, correct current setting technique based on Welding Control Condition Table (WCCT) has to be established. While detection technique requires driver check by production operator five times per day. Based on detection rating table, these two techniques may detect the defects where control is based on variable gauging after parts have left the station. Ranking 5 has been identified for the detection value. RPN was determined at 80 \( (S, 8) \times (O, 2) \times (D, 5) \). Objective of the recommended action is to reduce occurrence and detection value by implementing one-piece confirmation for each activity before SWP begins. Detection value is decreased to 4 after recommended action was taken. There is a good chance for detection with error detection in subsequent operations or gauging performance on set up and first-piece check (for set-up causes only). New RPN was determined at 64 \( (S, 8) \times (O, 2) \times (D, 4) \).

### Control Plan in Spot Welding Process

During SWP (Tables 3 & 4), all child parts have been assembled, where welding spot machine (WSS) is used to run the process. Characteristics have been identified for products (spot point quantity and appearance) and for process (parameter setting, tip dressing and twist test). Under product characteristics, spot point quantity is stated in the Assembly Operation Sheet (AOS) released by the customer. From that point, the supplier as reference for customer’s requirements uses AOS, whereby detailed requirements are explained in sequence on how to assemble each part together. Appearance needs to be controlled not only for the assembly parts but also for the other parts as well, such as the stamping and injection parts. Burr or sharp edge is one of the defective results for appearance.

Process’ characteristics for spot welding act as the main references for the plant maintenance (PM) supervisor. In some cases, problems have occurred because the standard is not being complied to. For example, situations of no fusion or no nugget can happen and this causes the parts to be categorized as critical characteristics (CC). The potential effects of failure to the customer may include detached components during the endurance or driving session that can endanger the driver or passenger.

Tip dressing activity is conducted as per the standard operation procedures (SOP) requirements. This is to ensure all the tips that are used during production stage can supply the sufficient electricity level as defined in the control table and to avoid no fusion or no nugget conditions. During this activity, twist test was also conducted by the QC Inspector after several parts had been produced. The objective of conducting this test is to identify the required electricity level to be applied to the tip. Twist test requires the parts to be clamped together using G-clamper and force be applied directly to these clamped parts using the torque machine until the parts are detached from each other. The result from torque machine is recorded to check whether it is within the specification. If it is, this means, that is the right electricity level needs to be used. If not, action plans, for instance re-conduct twist test or redefined parameter

<table>
<thead>
<tr>
<th>Potential failure mode</th>
<th>Potential effects of failure</th>
<th>S</th>
<th>Class</th>
<th>Potential cause(s) of failure</th>
<th>O</th>
<th>D</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong spot location</td>
<td>Variation between parts</td>
<td>7</td>
<td>SC</td>
<td>Negligence of operator</td>
<td>1</td>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gun triggered before confirming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missed spot</td>
<td>Variation between parts</td>
<td>7</td>
<td>SC</td>
<td>Negligence of operator</td>
<td>1</td>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>No fusion</td>
<td>Child parts easy to detached</td>
<td>8</td>
<td>SC</td>
<td>Not enough current</td>
<td>2</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tip wear &amp; tear</td>
<td>1</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>Spot hole</td>
<td>Spot point damage (hole)</td>
<td>8</td>
<td>SC</td>
<td>Spot angle not perpendicular to surface</td>
<td>1</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Crack at tip surface</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SC, significant characteristics; S, severity; O, occurrence; D, detection; and RPN, Risk Priority Number
setting, need to be implemented so that result is within the specification.

Appearance characteristic does not have to use the SOP (Table 4) but only have to make sure that the parts are free from defect. On the other hand, all characteristics, except for tip dressing activity, use visual inspection method. However, for tip dressing activity, vernier caliper and tip gauge is used as the measuring equipments.

For spot point activity, additional job needs to be done to mark each spot point on the parts. During this process, operator has to confirm the quantity of spot points by marking using permanent marker pen. In case, number of actual spot points is not similar to the spot points stated in SOP, the operator has to exclude the parts from the others. This is to avoid the not good parts being used in the next process. Sample is divided into two categories (size and frequency). Sample size for spot point quantity characteristic is 100% of checking and marking. On the other hand, sample size for twist test and appearance are one piece per lot and one per every two hours, respectively. QC inspector, line keeper and also the operator are responsible to conduct the measuring activity.

Hence, all findings during the inspection activity are recorded into the projection weld check sheet for parameter setting, tip dressing frequency check sheet for tip dressing activity, spot point quantity check sheet for spot point activity and spot weld inspection check sheet for twist test activity. Almost all of the reaction plans in this case need to be referred to the supervisor for the next action plan. Therefore, it is imperative to have an experienced and well-trained supervisor to be responsible. Input of control plan comes actually from
the outputs of PFMEA. Thus, PFMEA and control plan have direct relationship and need to be in line for continuous improvement of product quality.

**P0 and P1 Comparison Data Analysis**

Five samples were produced during P0 stage. Built up activity was started at body no. 10, and accuracy for part produced was 85%. During assembly process, supplier only assembled child parts disregard their accuracy level, process sequences, preventive and detective actions to reduce and eliminate the failure effects. Supplier depends to AOS provided by customer and SOP that extracted from the AOS. Any potential failures would not highlight and supplier would not know the effect of conducting assembly process. First built up was achieved at 81% accuracy based on try and error methodology. Supplier needed to assemble all child parts together until completed the final product, which was inspected using inspection jig. Adjustment activity was based on the result of inspection achieved.

After first built up, next built up refers to the first sample as a master sample. Supplier’s intention was the next built up should be better compared to the first built up. However, second built up for body no. 18-1 only achieved 59% accuracy. Supplier implemented try and error methodology to improve part’s quality in terms of accuracy level. As a result, real causes of failures were not detected and repeated along P0 stage. Analysis was conducted to find the root cause. One of the element found was number of inspection points were different between first (43) and second (44) built ups. If the supplier had a structured documented procedure to record all the changes during the development stage like PFMEA and CP, those problems could be tracked and prevented.

Body no. 18-2 was built after some adjustment activity conducted at the assembly jig. The activity involved added and reduced shim to guide the part during assembly process. Accuracy data for body no. 18-2 was 63%, which was not sufficient to pass P0 stage. Analysis was conducted and again the number of inspection points was reduced to 43 points. There was no evidence to proof why this problem occurred.

QC Inspector could not define the use of different number of inspection points in the same inspection check sheet. However, if PFMEA and CP are implemented during P0 stage, these tribulations are recorded and the action plans are ready to improve the situation. QC Inspector also has the same understanding to implement the necessary actions based on the CP recommendations to improve the situation.

Body no. 22 was built after some modifications and improvements were conducted to improve the child parts accuracy level. Inspection check sheet was used during P0 stage and number of inspection points was fixed at 40 points. Assembly process was continued and the final accuracy was 78%.

Body no. 23 was produced. After the inspection and validation activities conducted, accuracy result was 70%. Again, there was no consistency of the accuracy of parts produced. One of the main objectives for PFMEA and CP being developed is to ensure any potential failures during manufacturing process can be eliminated or reduced. Severity of failures is a priority based on the severity-rating table\(^{13}\), where severity numbers are already classified into the criticality and significantly of the process to the parts produced. Therefore, criticality and significantly of the process were defined into categories to ensure the highest severity becomes a main priority to improve the situation. Thus, the right actions are already taken before the potential failures happen in order to improve the quality levels.

**Achievements in P1 Stage**

There are 17 prototype parts of FFSALH produced during P0 and P1 stages (Fig. 3) produced in accordance to PFMEA and CP methodologies. First three parts were produced to understand assembly jig and inspection jig capabilities and to act as the benchmark before actual process begins. Data was calculated and the results were 86.11% for both parts labeled as additional 1 and 2. But, for additional 3, data increased to 88.89% after some assembly jig adjustment activities were conducted. Data accuracy was calculated based on the total good points divided by total inspection points (36, including X, Y and Z directions). Main objective of P1 is to achieve at least 85% parts accuracy before the parts could be delivered to customer. Since data accuracy for parts labeled as additional 1, 2 and 3 have reached 85%, thus this allows for the build up activity to begin.

Rest of the body parts were actual parts used for P1 stage. First build up was conducted on body no. 144. Data was calculated and the result was 86.11%. Based on inspection points, there were 5 points out of specification from the total of 36 points. The activity continued with body no. 145, with result still at 86.11%. For body no. 146 and 149, data accuracy dropped to 83.33%. This occurred due to wrong parts setting during the assembly process. This was proven by the data.
produced in Y and Z directions for both body no. For A-2 data, the Z-direction for body no. 146 was lower (1.3 mm). This means the part was out of specification because it moved 0.3 mm downwards. For B-1 data, Y-direction for body no. 149 was 1.5 mm out of specification, which means, this part had moved 0.5 mm to the left from the correct position. Based on the PFMEA and CP methodologies, main cause for wrong part setting is negligence among operators during the assembly process. Necessary action should be taken based on PFMEA and CP recommendations to prevent it from recurring in the future.

Body no. 152 and 153 were built after necessary actions were implemented to improve part accuracy. The results for both body numbers were recorded at 86.11%. Build up activity continued to produce more body parts. Body no. 156 and 158 were built and this time, the result was recorded at 88.89%. The last body was built for body number 160 and accuracy was recorded at 86.11%.

Most critical area contributed to the lowest inspection points was at Y-direction for A-3, A-4, B-1, B-2 and C areas. Nevertheless, for E area at Z-direction was recorded as the main contributor for the data dropped.

Conclusions
Integration between PFMEA and CP techniques has been successfully achieved to improve accuracy level of parts being produced by detecting the potential failure modes and effects of failures in earlier stage and recognizing required actions to reduce and eliminate effects of failures. This helps in terms of reduced warranty claim from customer, reputation and improved productivity, company’s image and reputation and customer’s confidence. Minimum target for accuracy (85%) has also been successfully met during P0 and P1 stages were analyzed to see the effect prior to and after PFMEA and CP implementation. In P0, there was inconsistency of accuracy which makes it difficult to recognize the root cause of problems and thus, more difficult to recognize the required actions to be taken. However, in P1 stage, most of the parts were consistent and achieved the target. It was resulted from the integration and implementation of PFMEA and CP techniques during the parts development process as any potential failure modes are highlighted and immediate corrective actions are taken.

References


