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Analysis and Design of Slow Build Studies During Sheet Metal Assembly Validations

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ABSTRACT

Several manufacturers are adopting six sigma programs in efforts to reduce stamping variation. This requires the crucial step of establishing dimensional relationships for the stamping dimensional outputs that become key process inputs to the assembly process. This paper describes a methodology used to determine the root cause of dimensional changes in a front door assembly. Among the key findings in this study are the importance of understanding the effects of the datum-locating scheme and the significant influence of assembly processing variables, rather than stamping variability, on the final door assembly dimensional quality.

INTRODUCTION

Automotive manufacturers must develop new products in shorter periods of time and with ever increasing quality standards. Typically, quality goals are set for different stages of the vehicle development process. One of the main challenges is to meet or exceed these goals while maintaining the program scheduling constraints. Finding ways to reduce the time and cost spent in decision making and problem solving represents a major area of concern. One of the critical tasks during new vehicle development is the manufacturing validation of stamping and metal assembly parts within the automotive body or body-in-white. Since the automotive body provides the foundation for the vehicle, its dimensional integrity and functionality are critical to meeting the dimensional quality objectives for the overall vehicle. The sheet metal assembly process consists of a wide array of stamping components and lower level subassemblies that vary in rigidity and complexity. The lack of rigidity and process complexity results in dimensional relationships between components, subassemblies, and final bodies that are difficult to model. Engineers also face challenges identifying root causes of dimensional changes during the initial manufacturing process validation because volumes are low and individual components are dynamically changing as customer concerns are addressed.

One advantage of the early stages of an automotive model launch is that the low volumes and additional resources available give manufacturers the capability to better track parts through the production process without schedule disruptions. This approach also enables manufacturers to carry out dimensional studies to better understand the relationships and geometric changes between stamped components and their sheet metal assemblies. An effective technique to examine these dimensional relationships is to conduct a slow build study.

A slow build study involves tracking the dimensional changes that occur in a subassembly from stamping through each critical assembly operation (typically, the geometry set stations). Thus, stamped panels are first measured after stamping. These same panels are then re measured after each assembly operation with an assembly line. This approach differs from normal measurement where sheet metal assemblies are measured only at the end of the assembly line. The problem with this approach from a diagnostic standpoint is that manufacturers often are unable to quantify the effect of individual operations and often unnecessarily attribute assembly process variability to the stamped components.

One complication with using slow build assessments is that a large number of possibly correlated checkpoints are measured while the number of parts produced is relatively small. Typically, manufacturers produce subassemblies in groups or blocks of 5-20 vehicles during a launch. In addition, the location of part dimensions between stamped components and their assemblies also may differ, thus complicating the analysis. The methodology proposed later in this case study allows the estimation of regression models under these circumstances and provides a powerful tool for finding critical characteristics of components on their subassemblies and assemblies.

Several researchers have studied the sheet metal assembly process but few have concentrated on the validation of the process prior to production launch. Hammett (1995) showed that poor datum coordination or inconsistent set ups can cause assembly variation. Similarly, he found that the average mean bias for assembly dimensions is double the average of the stamping mean deviations. These findings conflict with the validation strategy of several manufacturers who focus more of their efforts on measuring and analyzing stamping dimensions than on resolving assembly concerns during manufacturing validation.

To better diagnose complex manufacturing variation relationships, several researchers have proposed methodologies. Takezawa (1980) used linear regression analysis to demonstrate that the assembly of sheet metal did not follow the rigid body additive theorem of variance. He showed that a rejected component could be assembled to an acceptable assembly, and also that an accepted component could be assembled into a rejected assembly. Lawless et al. (1999) discussed methods for studying variation in characteristics of products that have a multistage manufacturing process. The authors used simple regression, autoregressive models, and analysis of variance to identify stages with the largest contribution to the variation in the final product. Similarly, Hu and Wu (1992) developed a methodology based on principal component analysis (PCA) to identify variation patterns in an assembly process. Ceglarek and Shi (1996) studied the modeling and diagnosis of multi station sheet metal assembly with single faults. Later, Apley and Shi (1998) extended the study to develop a model for multiple fixture faults in multi stage panel assembly processes. Their model is based on least squares estimation and on part and fixture geometric information.

Multivariate methodologies for the study of complex problems, such as partial least squares and multiple response ridge regression, have gained some popularity in several industries such as chemical products. Breiman and Friedman (1997) examined different methodologies for predicting multivariate responses. Their results showed that for multiple response situations, the prediction accuracy improved by combining and analyzing the data in a multivariate manner versus the conventional approach of treating each response individually. This paper applies the partial least regression models to establish variation relationships during the analysis off a slow build study.

FRONT DOOR ASSEMBLY

DESCRIPTION

A front door assembly was studied using the slow build approach. Figure 1 illustrates this assembly. Its main components include the front door inner panel, two impact bars, and the front door outer panel.

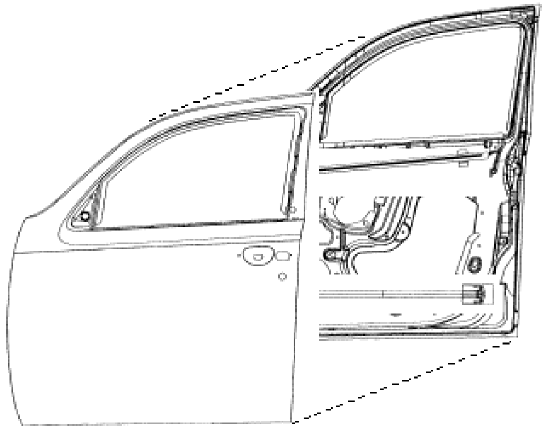

Figure 1. Front Door Assembly

The study was conducted using a portable coordinate measuring machine and an assembly fixture capable of locating the inner door panel, in-process subassemblies and the complete assembly. The corresponding locating scheme is illustrated on Figure 2.

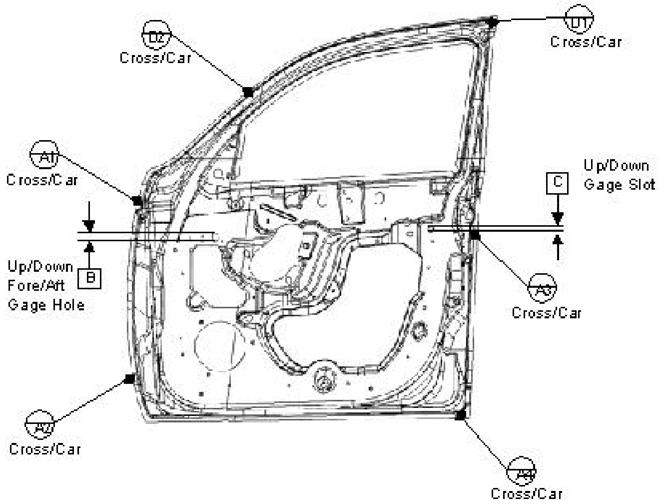

Figure 2. Locating Scheme Assembly Fixture

The purpose of this study is to improve the quality of the door assembly by reducing its level of variability and bringing its mean dimensions closer to their nominal engineering specifications. Table 1 shows the initial variability levels for the door dimensions and their respective capability levels during the initial validation phase using Pp and Ppk capability indices (Bothe, 1997). Pp is a measure of variation relative to engineering specifications, excluding the deviation of the mean from nominal; Ppk relates to producing parts within specification. In the automotive industry, Pp and Ppk capability indices greater than 1.67 are desired.

Table 1. Initial Capability – Front Door Assembly

# Checkpoints	% Pp<1.67	% Ppk<1.67	Avg Bias (mm)
27	37%	78%	0.68

The values in Table 1 show that the assembly had 37% of the checkpoints with a Pp less than 1.67, while the percent of off-centered checkpoints (i.e., fail Ppk) was significantly larger at 78%. The mean bias (absolute value of the mean deviation from target) was approximately 0.7 mm. Figure 3 presents the location of the checking points used in Table 1.

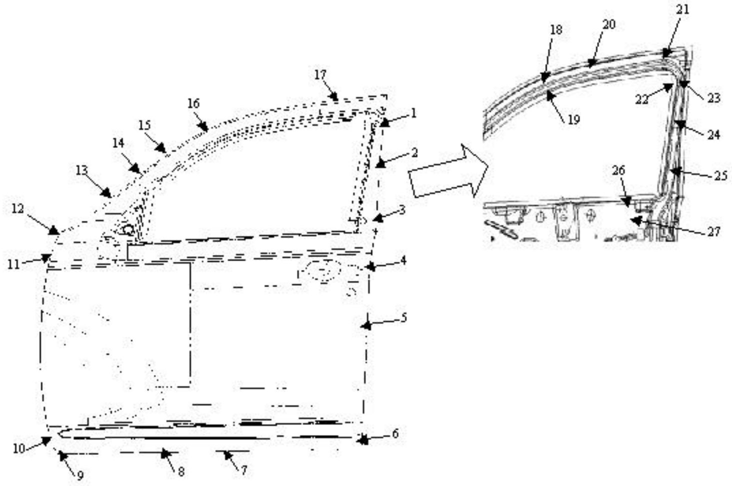

Figure 3. Door Assembly Checkpoints

The validation engineers for this manufacturing process were interested in whether these deviations resulted from deviations observed in the inner door panel. The dimensional quality values for front door inner panel stamped components are shown in Table 2.

Table 2. Initial Capability – Front Door Inner Panel

# Checkpoints	% Pp<1.67	% Ppk<1.67	Avg Bias (mm)
31	39%	65%	0.41

At first glance, it appears the capability levels of the inner panel roughly match those of the assembly. Nonetheless, the inner panel has 31 checkpoints that do not necessarily match the same location as those of the 27 checkpoints in the final assembly. More importantly, the front door inner panel and the final front door assembly are measured using different locating schemes and in different checking fixtures. In stamping, the door inner panel is rotated down from car position whereas the final door assembly is measured in car position. Figure 4 shows the location of the checkpoints measured in the stamped inner panel.

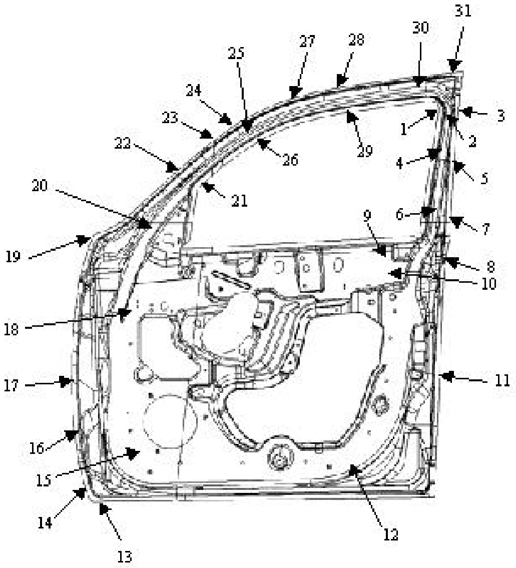

Figure 4. Front Door Inner Panel Checkpoints

We conducted a slow build study by tracking 15 different door inner panels throughout the various operations in the assembly process. The study was done in the assembly area using a portable measuring machine. Prior to performing the measurements, different alignment methods were investigated for the portable measuring machines; the results are attached in the appendix. Figure 5 illustrates the stages at which panels and subassemblies were measured.

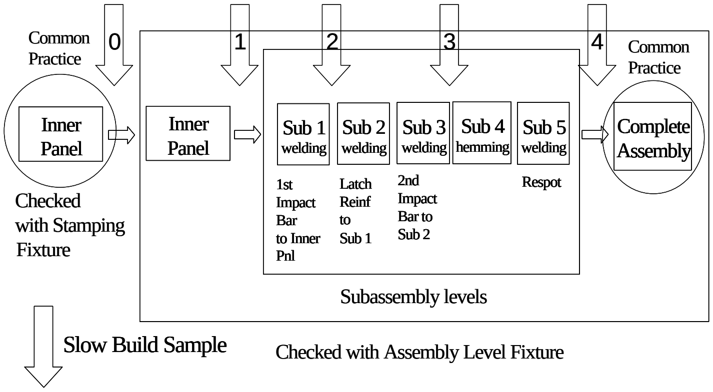

Figure 5. Slow Build Stages

DATA ANALYSIS

Partial least squares regression (PLSR) was used to analyze the data collected during the study. This methodology has previously been used in chemical engineering analysis and is robust to situations were the number of observations is small compared to the number of parameters in the model (Geladi and Kowalski, 1986; Kourti and MacGregor, 1996). The purpose of the methodology is to explain multiple response variables using a small number of combinations of the predictor variables (latent variables) that minimize the prediction error. Figure 6 illustrates the PLSR algorithm.

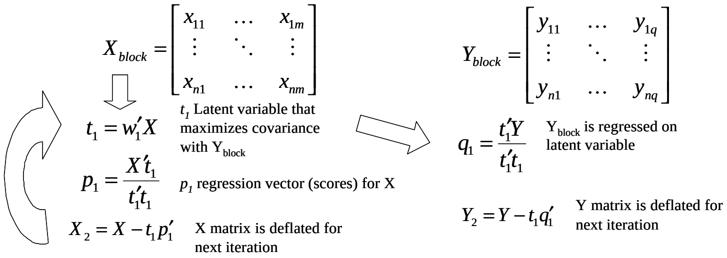

Figure 6. PLSR algorithm

RESULTS

The results of the data analysis indicate that while the front door inner panel has some influence in the first subassembly, explaining nearly 88% of the subassembly variation at this stage, its overall effect decreased as the assembly process went on. In the last assembly stage, the front door inner panel could only explain 25% of the final door assembly dimensions. These results are illustrated on Figure 7.

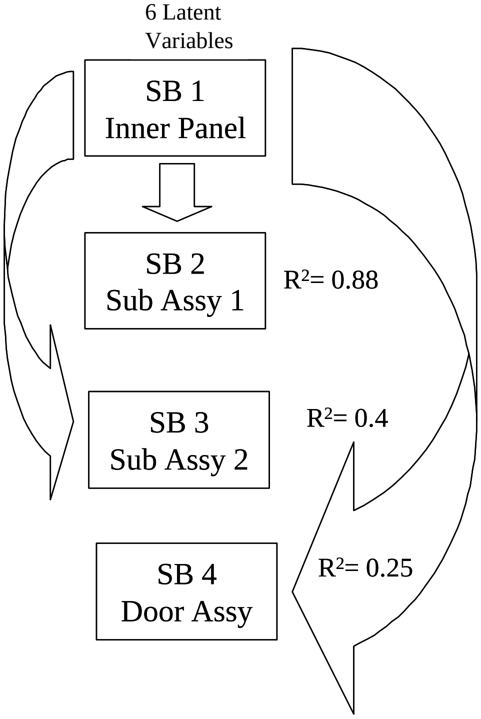

Figure 7. Door Inner Panel Influence

Contrary to the conventional expectation that assemblies are a direct result of the summation of their components, these results show that most of the dimensional changes are due to other sources. In this example, most of the final assembly variation may be attributed to changes in the locating schemes between assembly stations and the final hemming operation.

Figure 8 shows the most critical checkpoints in the inner panel from the slow build study. Again, these checkpoints have a significant influence in the geometry of the first subassembly, but ultimately have minimal influence on the final assembly.

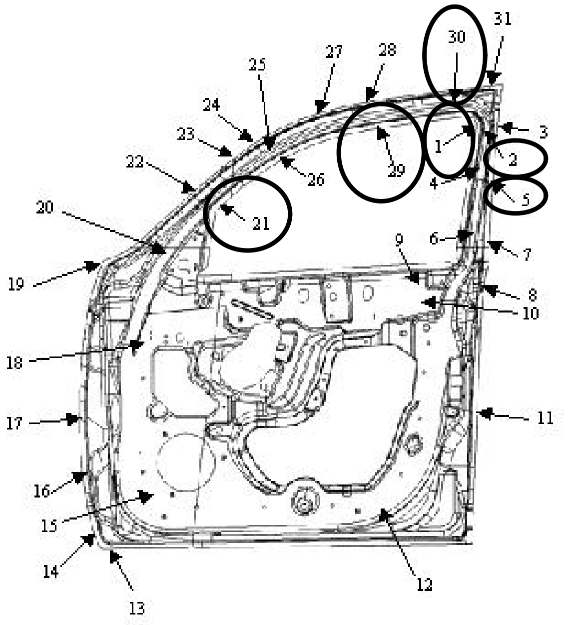

Figure 8. Significant Checkpoints – Inner Panel

After discovering the true impact of the inner stamping panels, this manufacturer shifted their variation reduction efforts to improving the robustness of the door assembly process. Some of the more important changes carried out were the adjustment of the hemming dies and the elimination of locating scheme differences between the first two assembly stations. Table 3 presents the capability levels of both the door assembly and the inner panels after the changes in the assembly process were conducted.

Table 3. Capability – Front Door Assembly

# Checkpoints	% Pp<1.67	% Ppk<1.67	Avg Bias (mm)
27	7%	56%	0.46

These results show a significant improvement in the overall variability of the door assembly. Before the slow build analysis, the percentage of checkpoints failing their Pp objective (i.e., Pp lower than 1.67) was 37%. After the changes, the percentage decreased to 7%. Similarly, the percentage of points failing Ppk decreased from 78% to 56%.

Interestingly, Table 4 presents the capability measures of the door inner panels after attempting to re-work some of the dimensional issues observed in the initial capability studies.

Table 4. Capability – Front Door Inner Panel

# Checkpoints	% Pp<1.67	% Ppk<1.67	Avg Bias (mm)
31	35%	62%	0.45

Compared to the initial capability of the inner panel, the stamped parts changed very little. The percentage of checkpoints meeting the Pp and Ppk criteria marginally improved. This result is in line with the findings of the slow build study, which demonstrated that the inner panel did not have a significant influence in the variation reduction efforts of the door assembly.

CONCLUSION

The validation of processes during the launch of a new vehicle is critical for the success of a program. Finding root causes of dimensional issues is a complex task. Multiple, correlated responses in a single assembly require the use of more complex analysis methodologies.

In this paper, a slow build study methodology was presented. The approach was validated on a case study of a door assembly. Using partial least squares regression to identify variation contributions, this approach helped direct the process improvement towards the assembly process, while a conventional approach would have focused on re-working dies of the inner stamping panel.

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APPENDIX

One of the main concerns with the use of portable coordinated measuring machines is the measurement error due to the inaccuracy of the alignment method used in a particular situation. Portable CMMs have the disadvantage of needing to be continuously re aligned to capture the coordinate system of the part that needs to be checked. In most instances, the alignment of the portable CMM can be based on the coordinate system of a checking fixture. Three different alignment methods were examined during this case study of the front door assembly. The alignment methods are described as follows:

1. Plane, Line, Point (3-2-1) Alignment: This method involves using the 3-2-1 principle by defining a plane, a line, and a point in a checking fixture and then using the nominal coordinates for the point as the main reference when aligning the portable CMM.

2. Sphere Referencing: In this method, three spheres on the checking fixture define the main coordinate plane; the coordinates of the center of the spheres provide the nominal values to define the final alignment for the portable CMM.

3. Best Surface Fit: In this method, three different datums in the checking fixture are digitized and, in a similar manner to the previous method, the nominal values are used to create a reference plane that is the main coordinate reference for the CMM.

The previous three methods were evaluated by analyzing the repeatability of the measurements using the checking fixture for the door inner panel. Five measurements of selected datums were taken under the three different alignment methods. The fixture is illustrated in Figure 9 and the results of the data analysis are presented in Table 5.

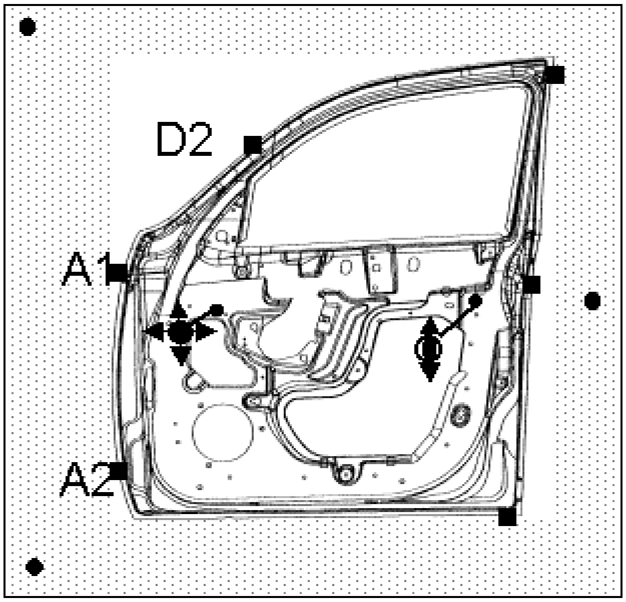

Figure 9. Checking Fixture Door Inner Panel

Table 5. Repeatability of Alignment Methods in the Front Door Inner Panel

Datum	Alignment Method	Average Absolute Deviation
A2	1	0.15
	2	0.22
	3	0.25
A1	1	0.00
	2	0.30
	3	0.35
D2	1	0.10
	2	0.74
	3	0.65

The results indicate that the first method based on the 3-2-1 principle of defining a plane, a line and a point in the checking fixture has the lowest measurement error resulting from re alignment. Based on this result, the 3-2-1 alignment method was used in the slow build experiments performed in this case study.