INTEGRATING 3D NON-CONTACT MEASUREMENT IN THE DIE TRYOUT BUSINESS PROCESS

Prepared by:

Digital Body Development System Project
University of Michigan Transportation Research Institute

May, 2008

Technical Report Documentation Page

1. Report No. UMTRI-2008-30	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Integrating 3D Non-Contact Measurement in the Die Tryout Business Process		5. Report Date May 2008 6. Performing Organization Code
7. Author(s) Pat Hammett, Steve Geddes, and Luis Guzman		8. Performing Organization Report No. UMTRI-2008-30
9. Performing Organization Name and Address University of Michigan Transportation Research Institute (UMTRI) 2901 Baxter Road Ann Arbor, MI 48109-2150		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 053316
12. Sponsoring Agency Name and Address Center for Automotive Research 1000 Victors Way, Suite 200 Ann Arbor, MI 48108 National Institute of Standards and Technology 100 Bureau Drive, Stop 1070 Gaithersburg, MD 20899-1070		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Based on two surveys of manufacturers, this report summarizes several automotive body die tryout buyoff criteria, rework processes, and 3D non-contact measurement strategies. Relative to historical die tryout performance levels, a significant reduction in the number of iterations is clearly achievable through the following:

- Improved ability to create die compensation models to create new machine files to rework parts closer to nominal without significant unintended consequences.
- Changes to existing die and production source part approval processes to make better decisions about when rework is needed to produce a dimensionally acceptable body.

Related to these improvements is the need for an effective business process integrating 3DNC measurement with new part approval processes to help manufacturers reduce the number of die rework iterations. A cowl top case study demonstrates the application of this process in effective use of 3DNC measurement to reduce the number of tryout iterations to only one rework loop.

17. Key Words 3D non-contact measurement, 3DNC, die tryout, tryout iterations, rework process, automotive part manufacturing		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 39	22. Price

Table of Contents

Die Rework Analysis Project Team

Primary External Research Team

Pat Hammett, University of Michigan

Steve Geddes, University of Michigan

Luis Guzman, University of Michigan

Richard Gerth, Center for Automotive Research

Industry Partner Core Team

American Tooling Center

Atlas Tool

Ford Motor Company

General Motors

Executive Summary

Past automotive body development studies have indicated that for medium to complex parts, tryout at the die source often involves excessive rework iterations. The primary reasons for this can be summarized as:

1. Difficulty in identifying the physical die modifications to simultaneously shift all critical out-of-specification features to their design nominal without unintended consequences in other part areas.
2. Inconsistency in the application of part approval processes in determining when die rework is required versus when it is better to accept an off-nominal condition because the part does not adversely affect final body assembly quality.

To establish a baseline of current die tryout practices, this report summarizes two surveys with follow-up interviews from industry participants. The first survey examines part dimensional requirements and approval processes across several North American manufacturers. The survey responses indicate some significant differences across manufacturers, but also several areas of commonality. One finding is that part approval processes for those parts produced internally by a body manufacturer often differ from those of its die suppliers. Another finding is that several manufacturers deviate from current industry-standard recommendations for automotive components outlined in the Automotive Industry Action Group's *Production Part Approval Process (PPAP)*. The surveys do confirm that body manufacturers recognize the limitations in applying the standard PPAP criteria for stamped components within a body assembly and opportunities exist to develop a more effective dimensional part approval process.

The second survey examines current efforts across manufacturers to integrate 3D non-contact (3DNC) measurement within their die tryout processes. It focuses on the usage of 3DNC measurement for both dimensional evaluation and identification of die modification recommendations to improve dimensional conformance. The survey results confirm that the use of 3DNC measurement for such activities is an enabler for improving die tryout performance. Still, manufacturers are developing their business processes and best practices for using it.

From these surveys and through this research project, we have compiled a generic die tryout business process and a set of die source buyoff and production source part approval processes. These recommendations incorporate 3D non-contact measurement, the elimination of

a Ppk criterion, and the usage of coordinated part-assembly builds (either virtually or physically) to evaluate mean bias conditions with the intent of minimizing unnecessary die rework iterations. Where die rework is deemed necessary, we assert that the utilization of 3D non-contact measurement data is critical for establishing effective die compensation models that reduce the number of rework iterations to a goal of no more than one. In this report, we demonstrate the application of this process using a case study from a cowl body panel. The business process was successfully applied to reduce the number of iterations to one.

1. Introduction

As manufacturers strive to reduce product development costs and time, improving die tryout performance remains a critical goal. Manufacturers seek to reduce both the total time and number of hours required for die tryout. For example, past studies indicate that for medium to complex parts the typical number of die tryout iterations from the end-of-die construction to die source part approval may range from five to nine[1] over a nine-to-14 week period using typical North American manufacturers' tolerances and part acceptance criteria (Hammett et al., 2007).

The primary reasons for excessive die tryout iterations and hours are related to the following:

1. Difficulty in developing die CAD models (i.e., die compensation models) that accurately compensate for metal flow and springback issues so that all critical features of the final product are centered at design nominal.
2. Difficulty in identifying the physical die modifications to simultaneously shift all critical out-of-specification features to their design nominal without unintended consequences in other part areas.
3. Inconsistency in the application of part approval processes in determining when die rework is required versus when it is better to accept an off-nominal condition because the part does not adversely affect final body assembly quality.

Although advances in many simulation and math-based die development tools have improved tryout performance, they have not been sufficient to allow manufacturers to produce medium to complex parts without any physical die rework. So, while continual improvements are necessary in these tools (i.e., to mitigate issue 1 above), the focus of this research is how to minimize the number of die rework iterations to no more than one.

Advances in 3D non-contact measurement (3DNC) technology and supporting software tools are providing the means to help manufacturers achieve this goal. In fact, several case studies within this research project have met this goal through the combination of effectively

[1] The definition of a die tryout trial or iteration is subjective and may vary by manufacturer. For purposes of this report, we define a trial or iteration as any event in which one or more dies in the die lineup (set) are reworked and a new panel is produced requiring a measurement inspection and evaluation.

integrating 3DNC measurement within a standard die tryout business process and adopting coordinated part-assembly build evaluations to support part approval processes. Of note, while 3DNC and related analysis tools provide valuable information, the ability to meet the one iteration or less objective still requires a combination of knowing when rework is actually needed to meet final body assembly quality objectives and the “what to” and “by how much” to physically adjust the dies to meet part acceptance requirements. Thus, the recommendations contained in this report are aimed at helping manufacturers obtain the required information to make these decisions and identify the best physical die rework modifications.

This report is organized into six sections. Section 2 compares part dimensional requirements and approval processes across several North American manufacturers. Section 3 compares current efforts at integrating 3DNC measurement within a manufacturers’ die tryout process. Section 4 provides a generic die tryout business process that integrates 3DNC measurement along with coordinated part assembly evaluations to support part approval. Section 5 provides a case study demonstrating the application of this process. Finally, Section 6 summarizes the main report findings.

2. Current Practices: Dimensional Requirements and Approval Processes

To establish a baseline of current practices among manufacturers, we conducted a written survey along with follow-up interviews of industry participants in this research study. The survey participants include die manufacturing and dimensional control experts from three North American automotive body manufacturers and two die suppliers. In the survey, we asked questions related to the four areas described in Table 1.

Table 1. Survey Topics -- Dimensional Requirements and Part Approval Criteria

	Topic Area	Description
	Measurement Systems	Measurement systems used for dimensional evaluations, part buyoff, and associated check fixture strategy.
	Measurement Point Selection and Tolerances	General rules for selecting part measurement dimensions and their associated tolerances.
	Die Source Part Approval Process and Criteria	Characterization of the process for approving parts at the die construction/tryout source and criteria used to determine part acceptance (buyoff).
	Home Line Part Approval Process and Criteria	Characterization of the process for approving parts at the production source and criteria used to determine part acceptance.

The survey responses indicate some significant differences across manufacturers, but also several areas of commonality. One finding is that part approval processes for parts produced internally by a body manufacturer may differ from those of its die suppliers. Another finding is that body manufacturers are deviating from industry-standard recommendations for automotive components outlined in the *Production Part Approval Process* or PPAP (*Production Part Approval Process*, 2002) to meet their own requirements. As such, they already have made some efforts to match their part approval practices with the challenges of body development versus simply adopting the standard PPAP guidelines. We believe this provides an opportunity to further refine approval practices to make more effective buyoff decisions for both internally-produced parts and those from external suppliers. We now summarize the results of the survey for each of the topic areas.

2.1 Measurement Systems and Inspection Points

Although all of the companies surveyed are using 3DNC measurement during die tryout, four of the five companies still maintain parallel systems for measuring parts. Here, they use conventional measurement systems for dimensional part buyoff and 3DNC systems for diagnostic support and analysis. As such, four of the five companies continue to build conventional measurement check fixtures (e.g., check fixtures with undercut surfaces to support part buyoff based on coordinate measurement machines (CMM), feeler gage checks, or measurement probes/data collection bushing). The one respondent who uses 3DNC measurement for both diagnostics and part buyoff uses low-cost part holding fixtures only (i.e., no undercut surface) with datum locators defined from part GD&T drawings. Of note, those respondents currently using 3DNC measurement primarily for diagnostics indicated that they were planning to move toward 3DNC to support part buyoff as well as diagnostics in the future.

Survey respondents also were asked to describe their current practices for establishing 3DNC measurement inspection points. With 3DNC measurement, even though the full surface is typically measured and characterized using color maps, manufacturers include discrete points to communicate dimensions of critical surfaces, trim edges, and other features such as holes and slots. Among these discrete point dimensions, most manufacturers use a classification system in which they identify a subset of the dimensions as critical, which must be manufactured within specification (i.e., hard points).

With 3DNC measurement, manufacturers tend to include an even larger number of discrete points than with conventional measurement systems to provide a comprehensive dimensional summary of the part. One reason for this approach is that unlike conventional systems, the number of discrete points does not significantly affect the inspection cost per panel with 3DNC measurement. In contrast, with conventional systems, the fewer the number of points, the less time it typically takes to measure a part. As such, manufacturers often minimize the number of measurement points with a conventional system to reduce inspection costs.

In terms of discrete inspection points, survey respondents indicate that they typically define them every 50 mm along a surface (see Figure 1 for a sample of measurements at incremental cross sections along a critical mating flange). Depending on the complexity of the surface, this interval may shorten or lengthen. Relatively long flat surfaces may be extended to every 100 mm; shorter lengths may be reduced to every 25 mm. Radial areas may be down to as low as 5 mm increments.

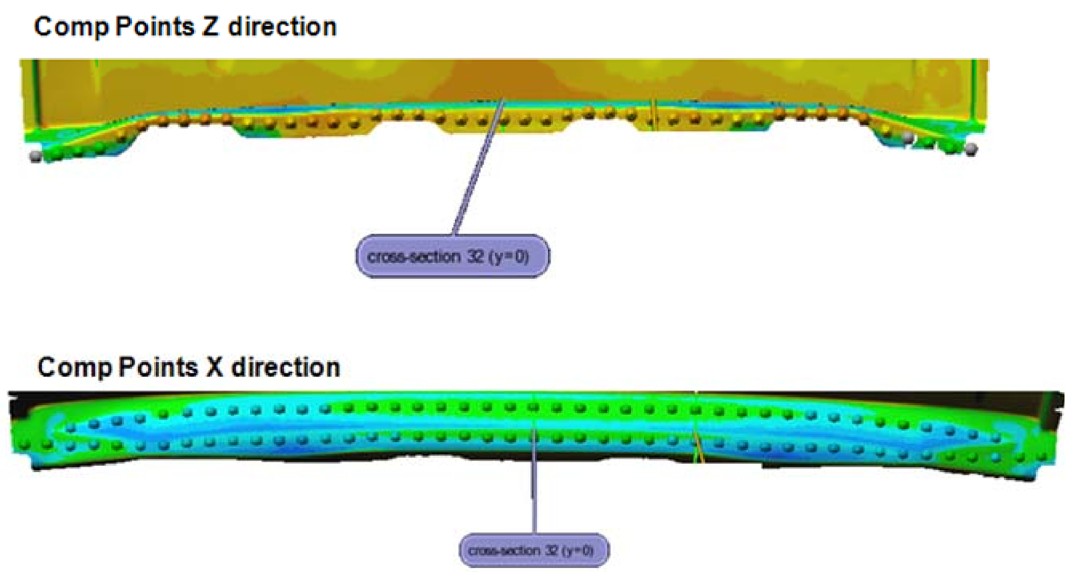


Figure 1. Cross-Section Surface Measurements for 3D Non-Contact Measurement

One issue in defining surface check points on mating flanges is their location relative to a flange radius and trim edge (see Figure 2). Respondents indicated that surface check points are typically placed at least ~5 mm (no less than 3 mm) away from both a trim edge and a radius.

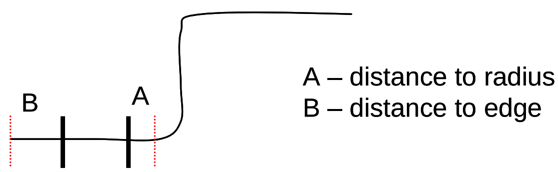


Figure 2. Check Point Selection Guidelines

For part approval, manufacturers typically inspect a combination of surface points, trim edge points, and holes (slots). The standard tolerances assigned for these feature types by the different North American manufacturers are fairly consistent. Table 2 shows typical original product design tolerances required for stamping part acceptance for these feature types. Of note, although these initial tolerance goals are similar, all respondents indicate that they routinely adjust them (either through re-target of mean dimensions or tolerance expansions) in order to obtain part buyoff. Respondents indicated that over 90% of parts involve *at least* one tolerance adjustment or nominal adjustment in order to meet their part approval criteria.

Table 2. Typical Industry Stamped Part Tolerances by Feature Type

Feature Type	Critical Feature	Non-Critical Feature (i.e., with general tolerance)
Mating or Interface Surface Point on Major Panel (e.g., Body Side Outer)	+/- 0.5 mm	+/- 1 ~1.5 mm
Mating Surface Point on Underbody Panel or Reinforcement	+/- 0.5 ~ 0.7 mm	+/- 1 ~1.5 mm
Trim Point on Major Panel (e.g., Bodyside Outer)	+/- 0.7 ~ 1.0 mm	+/- 1.5 mm
Round Hole Position	+/- 0.5 ~ 0.7 mm	+/- 1 ~1.5 mm
Round Hole Size	+/- 0.25	+/- 0.5 mm
Parallelism Requirement (e.g., body side to rear door interface)	0.5 ~ 1.0 mm	N/A

2.2 Die Source Part Approval Processes

Although the desired product design tolerance objectives for stamped parts are fairly consistent across manufacturers, the survey revealed significant differences in part approval criteria relative to these tolerances as well as in how parts are evaluated if original specifications are not achieved. Both of these issues have an impact on the number of die tryout iterations. Based on past dimensional performance, reducing the number of die tryout iterations to one or fewer will require acceptance of some dimensions that are outside their original design specification but do not adversely affect final assembly build quality. The fact that over 90% of stamped parts ultimately are approved for production with at least one dimensional specification adjustment (either a mean re-target or tolerance expansion) suggests that a manufacturer’s approach to dealing with out-specification conditions early in die tryout is a significant issue. In particular, the ability to sort out when to rework out-specification features versus when to leave the part alone is critical in minimizing the number of die tryout iterations.

Two of the three body manufacturers surveyed currently use coordinated part-assembly builds to help evaluate when rework is needed for parts produced at a die source. The other manufacturer is currently incorporating coordinated assembly builds[2] into its stamped part evaluation and dimensional approval process.

Coordinated part-assembly dimensional builds may be performed several ways. One manufacturer relies primarily on the use of production assembly tooling; the other respondents indicated the use of both production tooling and non-production tooling (e.g., use of a part coordination fixture or modular tooling). These comparisons are summarized in Table 3. Companies using non-production tooling typically do so primarily to support early die source buyoff and then use the production tooling for evaluations as they move closer to the start of regular production.

Table 3. Usage of Coordinated Assembly Build to Support Part Buyoff

Survey Question	OEM-1	OEM-2	OEM-3
For die source buyoff, is part approval based primarily on check fixture inspection results ***OR*** is it also based on Coordinated Part-Assembly Build?	Coordinated Assembly Build	Check Fixture Results	Coordinated Assembly Build
What type of fixture is used to build the assemblies and evaluate parts using coordinated assembly build?	Production Assembly Tooling	Non-Production Assembly Tooling	Non-Production Assembly Tooling

Other differences in approval practices relate to the number of samples and stamping runs required. Table 4 compares responses across the manufacturers. Two of the five respondents indicate using much smaller sample sizes to determine part acceptance. For example, one body manufacturer requires a sample size of six to make part acceptance decisions at die source buyoff, while suppliers are typically asked to measure 30-35 total samples.

[2] A coordinated assembly build involves assembling stamped parts with known dimensional deviations through the assembly process to determine how out-specification conditions affect next process assembly quality. For example, non-rigid stamping dimensions routinely change during assembly processes as a result of welding, a change in clamping conditions, the mating of a non-rigid component to a more rigid parts or subassemblies, etc.

Table 4. Die Source Buyoff Process and Part Approval Criteria

Survey Question	OEM-1	OEM-2	OEM-3	Supplier 1	Supplier 2
Use of 3DNC for Part Buyoff	Standard Practice	Use as Diagnostic	Use as Diagnostic	Use as Diagnostic	Use as Diagnostic
# of panels measured (sample size) on 'critical or key check points' for die source part buyoff	6 pc	5 pc with additional 25 pc sample	10 pc	5 pc with additional 25-30 pc sample	6 pc with additional 30 pc sample
# die setups (stamping runs) used to collect these panels for measurement	1 run	2 runs	1 run	1-2 runs	1-2 runs
Percent in Specification (e.g., PIST%) {PIST = # Points inside Specification Limits/ Total # Inspection Points}	> 80%	100%	> 80%	> 90%	> 95%
Pp/Ppk Criterion	Not Used	Pp > 1.33 and Ppk>0 (mean in-spec)	Ppk > 1.33 (Require 80% PIST and Pp > 1.33)	Pp and Ppk > 1.67	Pp and Ppk > 1.67

The issue of sample size has important implications in the adoption of 3DNC measurement to support part buyoff measurement studies. In general, the use of 3DNC measurement systems without robotics requires more operator time to measure a panel (versus using a CMM or a check fixture with data collection probes). Thus, adopting 3DNC for die source approval processes likely requires the use of smaller sample sizes or else the cost of inspection could be prohibitive. For instance, among the respondents, OEM-1 has the smallest sample size requirements, but also relies almost exclusively on 3DNC measurement for part buyoff. Hammett et al. (2006) have shown that reducing sample size to support full adoption of 3DNC measurement is a reasonable strategy given that within-run standard deviation for a stamping tryout run is relatively low and predictable based on past experiences. Thus, sample sizes of three to five are reasonable to make effective decisions particularly for mean off-nominal conditions. The use of small sample sizes per run also is justifiable if one repeats the measurements across multiple runs to ensure consistency in process setup.

Another major difference among manufacturers is the use of Pp/Ppk criteria for part acceptance decisions at die source buyoff (see Table 4). One body manufacturer evaluates internally-produced parts relative to Pp and Ppk criteria greater than 1.33; another does not use Pp/Ppk; and the third uses a Pp > 1.33 and Ppk > 0[3]. Interestingly, suppliers tend to have stricter criteria placed on them. Most suppliers of North American manufacturers are given a Ppk > 1.67

[3] Ppk > 0 essentially requires that the mean for each dimension lie within specification limits.

requirement for all inspection points. This criterion is related to PPAP guidelines (*Production Part Approval Process*, 2002).

Of note, *having* a stricter Ppk requirement for stamped parts does not imply actually achieving it. Companies using a Pp/Ppk criterion routinely adjust specifications to meet this quality requirement. Survey respondents estimate that at least 90% of all parts require at least one specification adjustment to meet approval criteria. Further, past studies suggest that 40-60% of component dimensions will likely require some specification adjustment to meet a Ppk > 1.67 for the tolerances identified in Table 4 above. These studies also show that the large majority of these dimensions that fail Ppk do not adversely affect final assembly build quality (Hammett et al., 1999).

The one manufacturer that is not using Pp/Ppk criteria (OEM-1) to evaluate stamping part quality uses a percent-in-specification metric (PIST[4]). For part buyoff, it requires a PIST score of 80% or higher and that any out-specification part conditions are approved through a coordinated part-assembly build evaluation. Of note, even this company, which uses the slightly looser PIST metric, still estimates that 80% of parts require some specification adjustment for part approval.

The reasoning for OEM-1's use of a low sample size part buyoff approach and PIST criteria versus Ppk may be summarized as follows. Evaluating the acceptability of stamped parts is primarily related to assessing mean bias from nominal conditions for its various dimensions and how these biases affect next-level assembly build quality. Since the inherent within-run standard deviation is predictable and relatively low, these mean bias conditions may be effectively characterized with relatively few samples (e.g., three to 10). As such, the usage of 3DNC measurement, while it may involve some tradeoffs with the desired number of measurement samples, still provides a comprehensive assessment of mean bias conditions across an entire part. Moreover, its advantages, such as greater ease in evaluating effects during an assembly process, more than offset potential concerns with smaller sample sizes. For example, one can more easily evaluate whether a slight twist in a stamped panel is getting magnified or minimized during an assembly process using 3DNC color maps than conventional tabular measurement output.

---

[4] PIST: Percent of inspection points that satisfy tolerances (or the percent of inspection points within specified tolerances)

The reduction of die tryout iterations to one or fewer will undoubtedly require acceptance of some out-specification conditions (i.e., fail a Ppk criterion) in non-critical part dimensional areas. These decisions often require coordinated part-assembly build evaluations, either virtually or physically, to confirm that they do not adversely affect an assembly dimensional conformance. Thus, regardless of how 3DNC measurement is integrated into the die source part evaluation process, the adoption of appropriate acceptance criteria and the usage of coordinated part-assembly build evaluations are critical to reducing the number of iterations.

2.3 Production Source Part Approval Process

Die source part acceptance criteria and the number of die tryout iterations also are affected by production source buyoff requirements. The reason is that stamping production sources do not want to perform any physical die rework once dies are shipped to their home line in a production facility. As such, a production source's willingness to accept deviations for out-specification part features at the die source is directly impacted by the likelihood of these same features being accepted at production source approval by their assembly customers. So, to minimize unnecessary rework at the die source, production part approval processes also must reflect the limitations of producing all stamping features within original design tolerances.

Table 5 compares part approval processes across three North American manufacturers. All of these manufacturers ultimately evaluate themselves using a Ppk criterion, but their approaches differ. We now discuss the differences.

Table 5. Production Source Buyoff Process and Part Approval Criteria

Survey Question	OEM-1	OEM-2	OEM-3
Use of 3DNC for Part Buyoff	Standard Practice	Use as Diagnostic	Use as Diagnostic
# of panels measured (sample size) on 'critical or key check points' for production source (home line) buyoff	9 pc	5 pc with additional 25 pc sample	30 pc
# die setups (stamping runs) used to collect these panels for measurement	3 runs	2 runs	1 run
Percent in Specification (e.g., PIST%) {PIST = # Points inside Specification Limits/ Total # Inspection Points}	100%	100%	100%
Pp/Ppk Criterion	Ppk > 1.33 (after mean re-targets)	Pp and Ppk > 1.33	Pp and Ppk > 1.33
Estimated Percentage of Parts Requiring Specification Adjustment (mean re-target or tolerance change)	~90%	~95%	~95%

The official industry PPAP standard involves measuring 100 samples from a run of 300 pieces using a Ppk > 1.67 criterion for all inspection points. Of note, all of the stamping manufacturers surveyed deviate from this recommendation and measure fewer panels for PPAP. They do so because of a high confidence that within-run standard deviation is low for a stamping process and that measuring a large sample from a single run is non-value added. Still, OEM-1, which uses 3DNC measurement to support part approval, measures the fewest samples at nine, though it should be noted that they spread them over three separate runs (setups).

For production part approval, OEM-1 measures three panels for each of three separate runs for a total of nine samples. Its adoption of 3DNC technology and its present limitations with large sample sizes has impacted its sampling methods. Also of note, while OEM-1 uses a Ppk criterion > 1.33 for internally-produced stamped parts, it does not apply this criterion until after approving mean deviations from nominal for various panel dimensions through coordinated assembly builds. In effect, OEM-1 is using coordinated assembly builds to evaluate mean bias conditions and a separate Pp criterion to evaluate variation conformance. Of note, if one sets the mean of the approved part as the new nominal (i.e., mean re-target), a Ppk > 1.33 criterion reduces to a Pp > 1.33. In contrast, the other two manufacturers use a Ppk criterion prior to approved mean offsets. Of note, they also are making specification adjustments (mean re-targets and/or tolerance expansions) to meet their Ppk criterion to achieve PPAP.

Although the development of a standard industry part approval process is not the focus of this research, the adoption of an appropriate part approval process does play a role in the number of die tryout iterations. In Section 3, we further discuss this issue after reviewing the current state of 3DNC measurement within our respondent companies. We then return to this issue with a set of recommendations for die source and production source dimensional approval criteria aimed at minimizing unnecessary die rework iterations.

3. Non-Contact Measurement Applications within the Die Tryout Process

Various 3DNC measurement systems are available for measuring stamping dies and related parts. In this section, we compare differences among manufacturers in the usage of these technologies within their respective die tryout processes (see Table 6). These technologies, along with related best practices, are still evolving. As such, the practices of today may vary significantly in the next ten years with further enhancements and as manufacturers better learn how to maximize the benefits of these technologies.

Table 6. Measurements and 3DNC Applications for First Panel Quality Review

Measurements - 1st Panel Review	A	B	C	D
Measure Finished Panel	Current Practice	Current Practice	Current Practice	Diagnostic Only
Measure Draw Operational Panel	Current Practice	Current Practice	Diagnostic Only	Future Practice
Digitize Draw Panel to create DIE CAD (Machine File) for Next Secondary Operation	Current Practice	Current Practice	Diagnostic Only	Future Practice
Measure Secondary Operational Panels from Form Dies	Current Practice	Current Practice	Diagnostic Only	Diagnostic Only
Measure Secondary Operational Panels Non-Form Dies (e.g., Trim)	Current Practice	Do not use	Diagnostic Only	Diagnostic Only
Make Part Acceptance Decisions based primarily on 3DNC Data (versus conventional check fixture)	Current Practice	Diagnostic Only	Current Practice	Diagnostic Only

As shown in the Table 6, most manufacturers utilize 3DNC measurement within their die tryout process for dies, operational panels, and finished panels. The techniques used to obtain these measurements are outlined in a prior report (Hammett et. al, 2007). This report focuses on applications of these measurements to support die tryout.

Most manufacturers are concluding that it is unnecessary to measure dies as long as they are cut to die machining CAD with no manual rework performed. Machining accuracy is such that the majority of surface measurements are within 0.05 mm of die CAD and nearly all points are within 0.1 mm (i.e., near the accuracy capabilities of 3DNC measurement for measuring dies). Still, die measurements may be deemed necessary if: existing die development files are not representative, dies are being duplicated from another set, or manual die rework has occurred.

In terms of stamped part measurement, most manufacturers collect 3DNC data for ***finished panel*** dimensional quality assessments even if they use conventional checking methods for part buyoff activities. The reason is that they prefer 3DNC measurements to conventional data collection reports for their comprehensiveness, visualization benefits, and ease of interpretation in making die rework modifications.

At present, some differences exist in the application of 3DNC toward measuring ***operational panels***. Operational panels, such as draw operational panels, are measurements made after an operation but prior to the final die in a lineup. The way in which operational panel information is used within the die tryout process is a determining factor in whether a company deems it useful to collect these measurements.

Among the potential usage for operational panel measurements include:

1. Diagnostics for dimensional problem solving,
2. Establishment of morphing rules (i.e., die rework recommendations) to modify die surfaces,
3. Establishment of die machine files for subsequent secondary operations

All companies indicate that they collect operational panel measurements for some diagnostics (e.g., application 1 above). Here, most companies measure operational panels after the draw die operation or other forming operations for diagnosing a particular forming problem. Some respondents, however, indicate a reluctance to perform these operational panel measurements due to low confidence in the ability to effectively locate the panels for measurement. Operational panel measurements involve using the following: a low-cost temporary holding fixture, an operational die as a fixture, or a fixture-less, free-state condition. The latter two options, in particular, can be problematic for non-rigid complex-shaped stamped panels. The one company that is routinely collecting operational panel measurements expressed confidence in its ability to quickly and cost-effectively produce temporary holding fixtures for reliable part measurements to mitigate this concern.

A second application of operational panel measurements relates to the usage of these data for establishing morphed die compensation models for physical die rework. As opposed to manual die rework, all companies indicate a *preference* to morph die development machining files and re-cut dies for any significant rework moves. This is particularly the case in rework involving the draw operation. In these cases, operational panel measurements may be used to help establish new die development machine files. Of note, in some cases, finished panel measurements alone provide sufficient information to establish these die rework moves, limiting the need for operational panel measurements.

A third application for operational panel measurements is to create die machine files for secondary die operations (e.g., subsequent trim operations after a forming operation). A main objective here is to reduce spotting time. The adoption of this practice currently varies across manufacturers. One manufacturer indicated that this approach was standard practice. Another indicated that it rarely uses this approach because it did not want to link secondary operation timing to completion of the draw die. Another indicated a similar concern related to timing of information. This survey respondent suggested that "Scanning draw panels for large parts to cut secondary operations could very well have a negative impact since a great deal of time could elapse making a good draw panel. However, if the draw panel does not nest properly on the draw post/cavity, scanning the draw panel to cut secondary tools becomes a much more viable tool."

In the event that die rework is deemed necessary for part acceptance, the decision to use 3DNC measurement to support die rework modifications is preferred by all companies. Two of the companies indicated that it was standard practice to make dimensional or form improvements in the dies based on 3DNC measurements. The others indicated a strong preference for 3DNC measurement, but noted that they decided on a case-by-case basis whether it was needed.

4. Recommended Die Tryout Business Process with 3D Non-Contact Measurement

In this section, we illustrate a generic die tryout business process flow incorporating 3DNC measurement. We present these recommendations using four business process flow charts:

- Flow 1 – Die tryout to first panel dimensional quality review (Figure 3)
- Flow 2 – Rework decision process (Figure 4)
- Flow 3 – Draw die rework process (Figure 5)
- Flow 4 – Secondary die operation rework process (Figure 6)

Presenting information in this format shows how 3DNC measurement may be integrated within the overall tryout process to help manufacturers reduce the number of tryout iterations. Within these flow charts, we note conditions where the usage of 3DNC to support a process step is not commonly agreed upon as standard practice using a decision box. We then discuss criteria and factors used by manufacturers in determining whether to use 3DNC for each particular process step.

4.1 Die Source Tryout to First Panel Dimensional Review

Figure 3 shows the initial flow within the first die tryout trial. Here, we assume a typical approach where manufacturers first seek to obtain a stable panel that meets all formability requirements. Most manufacturers will work on resolving formability issues prior to the consideration of dimensional issues. Hence, there may be some adjustments to process parameter settings, material selection, or die face conditions prior to dimensional reviews. For purposes of this research, we will consider these activities as part of die construction or within the first iteration in obtaining an initial panel ready for dimensional review.

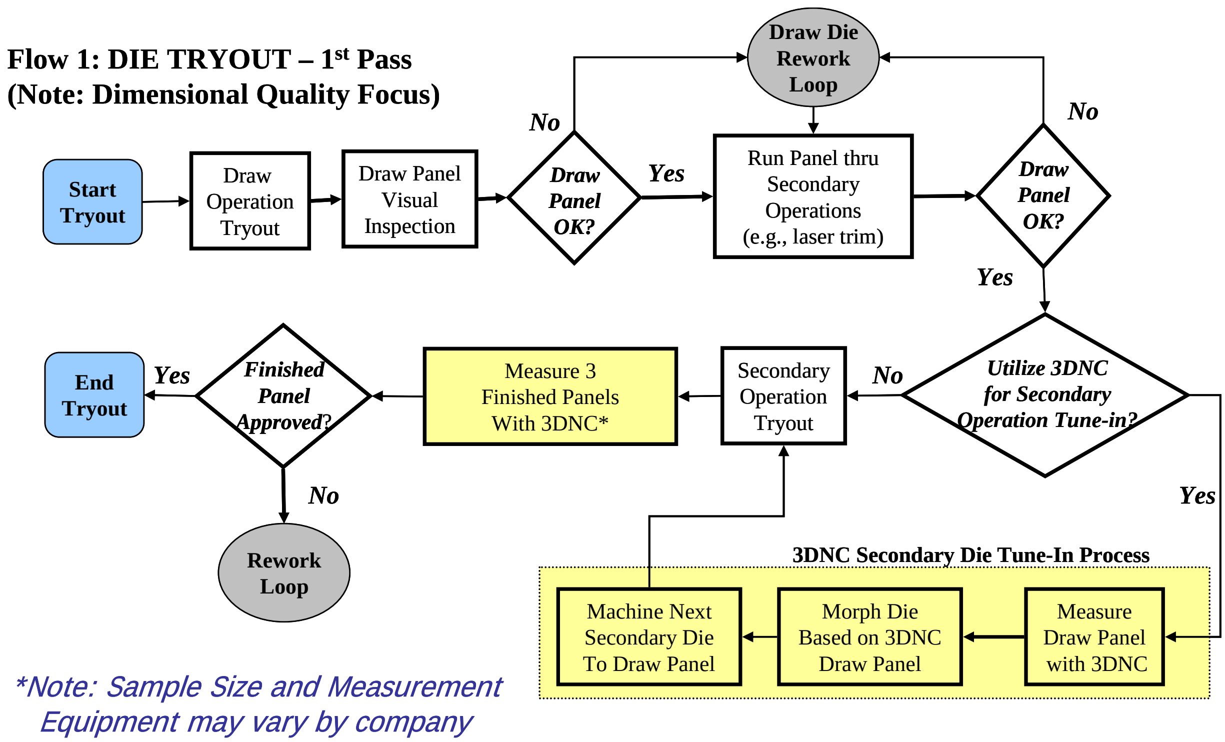


Figure 3. Die Tryout Process Flow – First Pass

For this first die tryout dimensional trial, we do not recommend measuring dies assuming that no manual rework has been done. Past studies have shown that dies are machined very close to their die machine CAD. Here, one may expect the majority of the die surfaces to be machined within 0.05 mm of die CAD and all within 0.10 mm. These levels are near the accuracy capability of 3DNC measurement systems for measuring a large die and within the inherent noise in establishing a relationship between a physical die dimension and a resultant part dimension. In other words, one would notlikely be able to correlate a change in a die of say 0.1 mm to a corresponding 0.1 mm shift in a part dimension (particularly for a surface dimension).

In those cases where die CAD math models are either unavailable or have been modified significantly during die construction, manufacturers may want to measure dies. Manufacturers may want a mathematical representation of the actual die surface for morphing rework activities or to account for press flex/deflection in mating dies in order to reduce spotting time. In the latter case, one may even want to measure lower and upper dies in order to perform a virtual die assembly as a diagnostic activity. Again, if dies are machined without manual rework, the die CAD machine development file should be sufficiently representative for any dimensional analysis activities.

Another issue during the first dimensional trial is whether to measure operational panels. Again, operational panels are those produced within the die lineup processes prior to a finished panel. Measuring operational panels is generally limited to operational draw panels or perhaps after a secondary forming operation.

Since measuring an operational panel involves extra data collection resources and is not required by next process customers, it is typically used only for one of two purposes. First, the measurement of an operational panel may be desired for diagnostic purposes before completing other secondary operations. For instance, a problem with a trim edge on a critical mating flange may be related to the panel shape after the draw operation and not the trim operation itself.

A second application for measuring and digitizing an operational panel is secondary operation tune-in. It has been shown that in those cases where a draw operational panel significantly deviates from product CAD, the use of draw operational panel measurements for creating a secondary operation die CAD may significantly reduce die spotting and tune-in time. The typical approach here is to measure the draw operational panel, convert to a digital representation (e.g., create a *.stl file or polygonal model), and then morph surfaces for the next secondary operation based on the operational panel measurements. The use of operational panels for secondary operation tune-in has largely occurred for the operation after draw[5]. Here, draw operational panels may significantly deviate from product CAD only to then shift toward product intent after die binder areas are removed.

As discussed earlier, the decision to use this secondary operation tune-in approach varies by manufacturer. Some consider this standard practice, while others do not want to link secondary operation machining to the draw operation as they are concerned that this may affect overall timing. In the cases observed in this research project, using operational panels for secondary tune-in has been successful. Still, we should note that it has not been shown as a *required* practice for all parts to meet die tryout performance objectives. As such, we leave it as a decision loop to be evaluated on a case-by-case basis.

---

[5] The latter operations in a die lineup typically are machined to product CAD.

In those cases where secondary operational panels are measured, we recommend creating a temporary holding fixture in alignment with the GD&T locating scheme. We also recommend measuring these fixtures on a surface plate to effectively locate and align the panel. Various software products (e.g., Tebis) offer the capability to quickly create low-cost 3DNC scanning bucks to effectively simulate normal part holding conditions (e.g., temporary scanning bucks may be made out of fiberboard with net points at datum locations). Of course, in some cases, a panel may be sufficiently rigid to measure effectively in a free state without a fixture.

4.2 Die Rework Process Flow

In cases where die rework is deemed necessary, an initial decision is whether to support such activity with 3DNC measurement (see Figure 4). In some cases, a rework decision may be simple and no additional measurements or morphing compensation models are needed. In this case, we assume that manufacturers will use conventional methods.

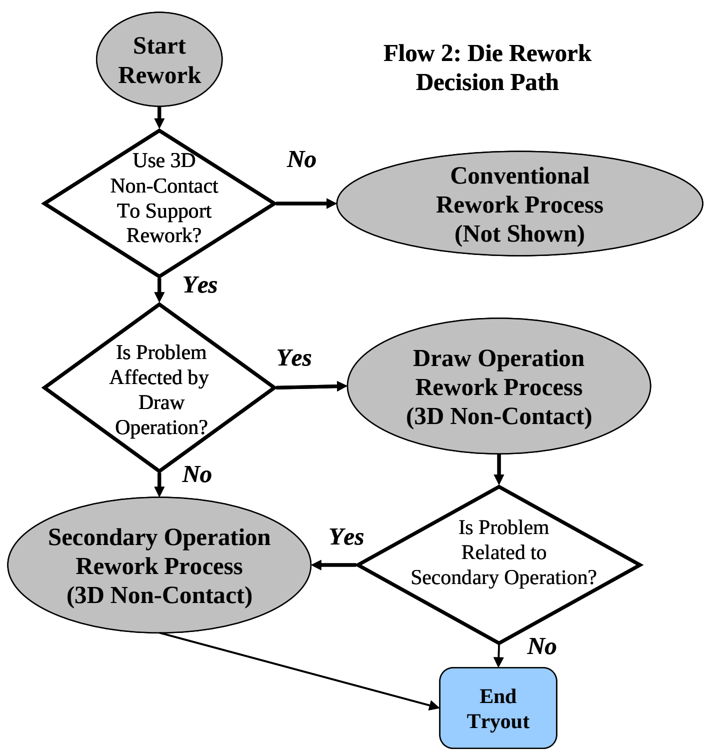


Figure 4. Die Rework Decision Path

For more difficult rework cases, we recommend using the following process which integrates 3DNC measurement. The first decision involves determining whether a rework move should be done in the draw operation (e.g., via re-machining) or a secondary operation. Based on the initial findings of this research, success has generally been greater with reworking a draw panel or a final forming operation versus other operational dies. Of note, this assumes that any significant rework involves more than a simple trim line or hole positional change.

Based on the cases gathered in this research and on interview comments, manufacturers may plan for one re-cut at the die source for any moderate-to-complex part to meet desired dimensional levels for part approval. This is particularly true for cases where die compensation prediction models significantly deviate from product design. Logically, the greater the compensation amount predicted by die modeling tools, the more likely the initial part will significantly deviate from nominal and require rework even if these *predicted* compensated effects are initially put into the die CAD.

Although one expects die compensation modeling tools to improve, the case studies in this research thus far suggest significant advances are needed. Interestingly, for the cases studied in this research, producing the draw die[6] to product design has been an effective strategy in minimizing overall timing (total time for die design, construction, and tryout). In certain cases where dies have been constructed to product design and a coordinated part-assembly evaluation strategy was utilized, parts were approved without any major rework loops. Furthermore, in some more complicated cases where die compensation away from product design ultimately was necessary to produce an acceptable panel, cutting the initial die to product design was not a hindrance. In these cases, the die manufacturer was able to effectively use 3DNC measurements to identify die rework modifications and create the new compensation model to achieve an acceptable panel in one re-cut. In comparison, for those cases where die compensation was incorporated initially based on prediction models, manufacturers still required at least one re-cut. Ultimately, the decision about whether to compensate initial draw dies away from product to account for expected springback is experienced-based and varies case by case. It is also a topic with varying opinions among die manufacturers and remains a t for future research.

---

[6] Compensation of male draw dies is a different issue. Here, manufacturers may compensate to account for press flex/deflection in order to minimize spotting time. This is generally not for dimensional reasons.

4.3 Draw Die and Secondary Die Rework

Once a manufacturer determines that rework is required and the change is isolated to a particular operation, we provide the following two flow charts to summarize rework processes. Figure 5 shows the rework flow for the draw die operation; Figure 6 shows a similar process for secondary operations. We now discuss the integration of 3DNC measurement for each of these.

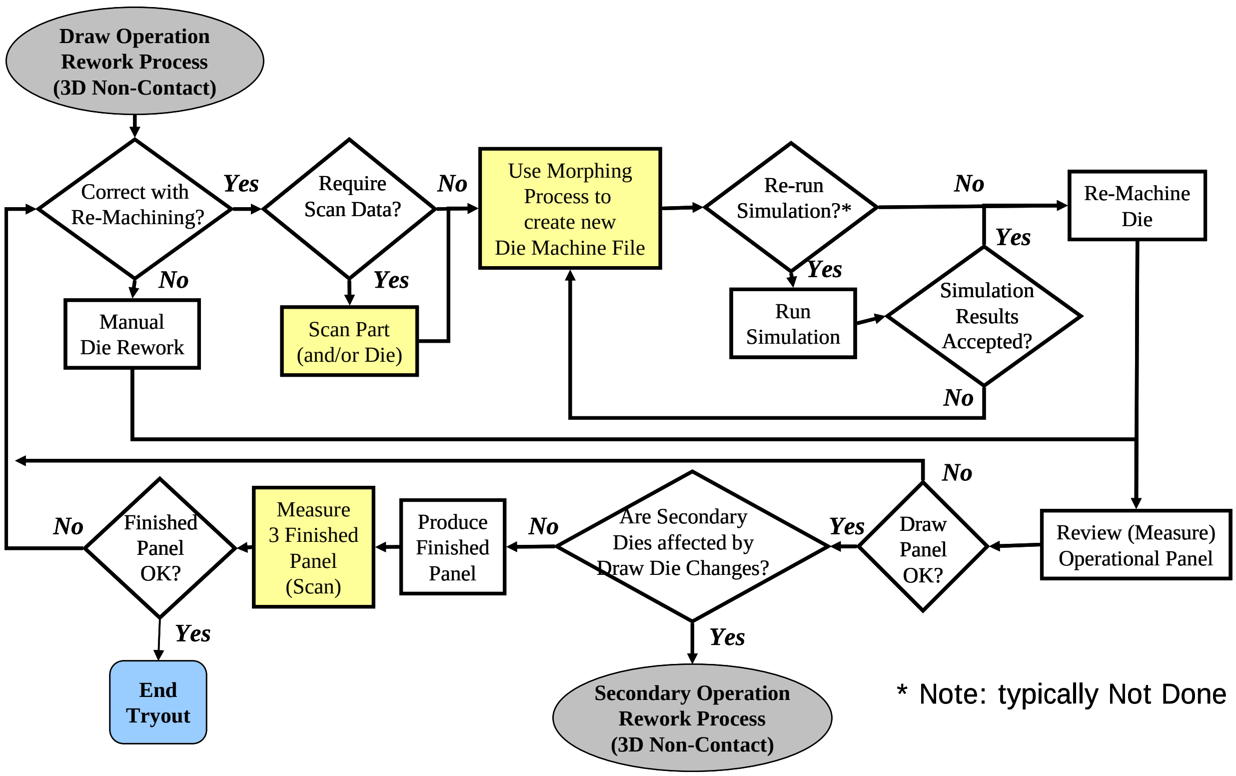


Figure 5. Draw Die Rework Flow

The first critical rework decision is whether to correct deviations with re-machining or manual rework. In general, manufacturers likely will choose to re-machine significant draw die rework issues, though exceptions may be made for a particular situation. Again, for re-machining, most manufacturers will morph existing die CAD or die measurements to create new machine files. Although morphing a draw die does not require scanned part measurement data, we believe that it provides the most comprehensive view for such an activity and is essential for incorporating multiple die rework modifications (i.e., rework moves in more than one area).

Again, if dies have not been manually reworked, they typically will not require 3DNC measurement. The original draw development CAD should be sufficient to use as a basis for creating a new, morphed die compensation model. However, if dies have been moved significantly away from their die CAD models, measuring the as-built die condition is recommended.

Various software tools (e.g., Tebis) are available for morphing dies to desired part conditions. Still, the establishment of best practices in applying these modeling rules is still evolving.

Most part dimensional rework is related to mating part flanges and their associated radii and trim edges. A simple correction to make is a one-for-one die modification. Here, one reworks the die surface opposite the part condition per the magnitude of the current part deviation. These deviations are usually gathered using 3DNC measurements of the part versus product CAD. In practice, a one-for-one relationship is often not the case. The part-die change ratio in a die rework correction condition typically varies from 2:1 to 1:0.5. For a 2:1 move, the die surface move is expected to be half the magnitude of the resultant part change. In other words, the part is expected to move twice the magnitude of the die correction. For a 1:0.5 move, the die surface move is expected to be twice the magnitude of the resultant part change. In other words, the part is expected to move half the magnitude of the die correction.

Die moves are further complicated by unintended consequences. In some cases, rework in one area will cause another area that is untouched during rework to shift out of specification. Thus, even if the die modification move is appropriate to fix a local condition, the overall part still may not be acceptable due to unintended consequences. This further supports the recommendation to compensate for mean off-nominal conditions in downstream assembly operations if possible rather than trying to rework dies.

The ability to build new die compensation models to re-machine dies that yield the intended changes is a critical skill needed to reduce the number of die tryout iterations. Although the training and development for such resources is beyond the scope of this research, its importance must be noted. Such a resource requires the skill combination of die making, 3DNC measurement, and CAD modeling. A discussion regarding best practices and evaluation methods for creating die rework compensation models shall be the subject of a future report.

Once an acceptable draw panel is produced, manufacturers may still need to resolve some dimensional concerns through secondary operation rework. The application of 3DNC measurement for such efforts is similar to the draw die rework process described above (see Figure 6). One difference is that the need for measuring an operational panel in a secondary operation is less likely than for a draw operational panel. In most cases, dimensional issues related to a secondary operation may be understood through inspection of 3DNC measurement data for the finished panel.

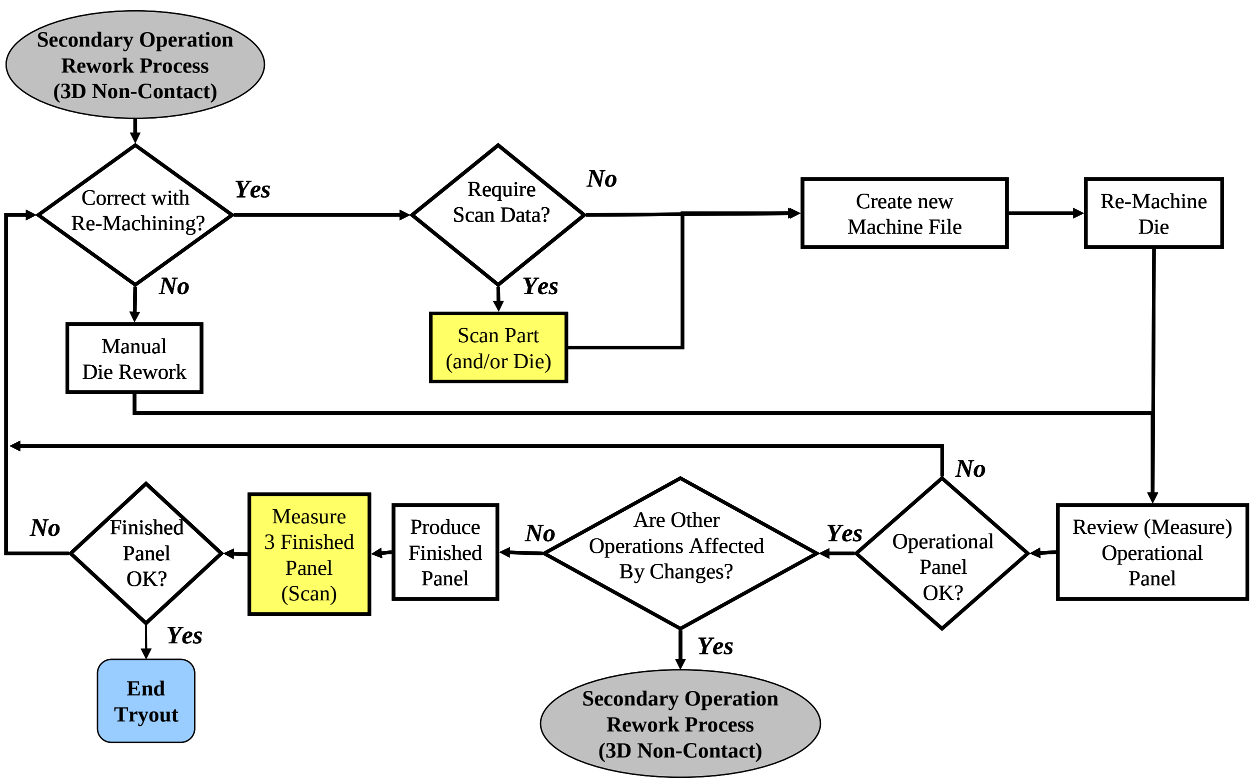


Figure 6. Secondary Die Operation Rework

4.4 Part Approval Criteria and Processes – Die and Production Source Approval

Once a visually acceptable finished panel is produced from initial die tryout, we recommend measuring a sample of five panels (or a minimum of three panels) using 3DNC measurement for part buyoff. Due to rigidity issues for many stamped parts, we recommend using a part locating fixture to perform the measurements. We assume that this fixture has been certified for accuracy (all locators within 0.1 mm of design) and that it passes a gage repeatability study (all dimensions achieve a gage repeatability of < 20%). With stamping part measurement, we do not see the need to evaluate reproducibility error as the majority of measurement system variation for stamped parts is related to repeatability (load/unload operation and datum schemes).

Since we recommend the adoption of 3DNC technology, we also do not see the need to measure panels with a conventional check system for buyoff runs. Of course, for some parts, it may be deemed appropriate to use a conventional checking method instead of 3DNC. For instance, a simple attribute check or conventional system may be all that is necessary for some parts. In these cases, using 3DNC in addition to conventional checking methods would be unnecessary.

To approve parts, we also recommend using a coordinated stamped part-assembly evaluation process to evaluate mean bias stack-up conditions. As a pre-condition for this activity, we recommend the following part submittal criteria:

Die Source Part Submittal Criteria for Coordinated Build Event

(Based on sample size of three to five)

1. All critical hard point features[7] are within specification.
2. 80% of all other dimensions are within specification.
3. Ranges for all dimensions are less than their tolerance width.

A key assumption with the adoption of these criteria is that stamped parts will be evaluated in next-level assembly processes for final part acceptance through coordinated stamping-assembly builds (e.g., assembly slow builds, panel matching builds, or part coordination fixture builds). The expectation is that these coordinated assembly builds will confirm that some out-specification conditions will not require rework and that mean re-targets and/or tolerance expansions may be appropriate for several dimensions.

---

[7] Hard point features are dimensions that cannot be compensated for in a downstream assembly process. For example, parallelism for a body side outer cut line to the door is likely a hard point. Hard point features must be defined prior to tryout.

The choice of a relatively small sample size during die source buyoff is based on the following reasoning. Stamping variation within a run is predictable and low relative to standard industry tolerances. This is particularly the case during early die source tryout where the material used is from the same batch, and processing issues such as automation and part handling have not been fully incorporated. In addition, the use of 3DNC measurements, even with a small sample size, typically may show any potential high variation concerns.

If possible, the three to five panels selected for measurement should be spread out over the tryout run versus taken consecutively. Of note, manufacturers may always measure a larger sample of panels if they historically have exhibited high within-run variation for a particular part and it is has caused problems in assembly.

The recommendation for a *minimum* of three panels is primarily to protect against data collection errors. During initial tryout, operators may be less experienced measuring a particular panel. With 3DNC measurement, certain features may be difficult to measure, particularly on an initial trial. As such, measuring only one or two panels could result in missing data on a part feature for one of the samples or, worse, mischaracterizing a mean bias condition.

Of course, increasing sample size always mitigates risk in data interpretation. Thus, if the cost per measurement using 3DNC may be reduced, sample sizes could be increased to 10 (or even 30) to improve statistical confidence of within-run variation estimates. However, measuring large samples, especially from a single stamping run, historically has been shown unnecessary to make effective decisions about part quality conformance.

As noted earlier, final production part approval criteria also may impact the number of die tryout iterations. Approving parts at the die source with out-specification conditions may depend on whether the stamping production sources believe they will receive similar approvals from their assembly customers. As such, we also recommend changes to the PPAP process in alignment with the above die source buyoff recommendations. Again, we recommend using a coordinated part-assembly evaluation process for assessing mean bias conditions. These guidelines/criteria for part submittal are as follows:

Production Source Part Submittal Requirements and Criteria

1. Measurement samples taken from three stamping runs (minimum of two runs)
2. Sample sizes of five per run (minimum of three and maximum of 10 per run)
3. Pp > 1.33 for all dimensions

Production Source Part Approval Criteria

1. All out-specification part dimensions must be accepted through coordinated part-assembly build event or by next process customer.
2. 100% conformance to specification for all dimensions. (Note: Criteria are expected to be applied after mean re-targets are completed based on acceptance at coordinated part-assembly build evaluations and documented through a functional master part process.)

Once approving out-specification conditions and resolving any variation issues through coordinated part-assembly build evaluations, we recommend the creation of a functional master part. A functional master part is a digital file of the most representative part condition (i.e., average part) and may be generated from various 3DNC software solutions (e.g., CogniTens or PolyWorks).

The purpose of a functional master part is to identify the nominal target conditions for the as-built part once it has been shown that it may produce a dimensionally acceptable body. Once a functional master part has been developed, future production stamping measurements should be maintained relative to this master part to ensure a consistent process.

We do not recommend that this functional master part replace the product CAD file. Instead, we recommend maintaining both digital representations over the life of a product, and archiving final dies to match the functional master part. This archiving is essential for making future die repairs or supporting reverse engineering/die duplication efforts.

5. Case Study – Cowl Inner Part – Observations and Analysis

We now illustrate this 3DNC die tryout business process using a case study for a cowl inner part (blank size:1575 x 650). The material for this part is a hot-dipped galvanized draw quality steel. This part is produced in a four-die lineup: (1) draw, (2) trim with pierce, (3) trim with pierce, and (4) flange.

For this case study, we first collected measurements at first panel dimensional review using a split-free panel without manual rework. Since no manual rework occurred, the dies were not measured (i.e., they were assumed to be very close to die machine file). Also of note for this case study, the draw die was machined to product design.

Finished panels were measured using both CMM and 3DNC measurement. As expected, certain areas of the part were not dimensionally acceptable at initial review and required rework. Specifically, of the CMM points, 27% of the dimensions were out-specification (PIST = 73%). Moreover, 50% of the points were out of specification using all of the 3DNC inspection points.

From this information, the die manufacturing team identified rework opportunities in five areas. They then morphed the draw die development model based on the 3DNC measurements of the draw operational panel and finished panel. They then re-machined the die to this new compensation model based largely on the finished panel measurements. With their rework changes, they were able to increase their PIST score to over 90% and get the panel approved in one rework iteration. The remainder of this section provides additional detail for this case.

5.1 Die and Part Dimensional Changes – Before and After Rework

To evaluate baseline part dimensional quality conditions, finished panels were measured using CMM, plus one panel was measured using 3DNC measurement[8]. The results from the 3DNC measurements are shown in Figure 7. As may be observed in the color map below, the part is significantly high in the center and low on the ends. In addition, the forward flange (top side of pictorial below) and the center portion of the rear flange (bottom side of pictorial) also are out of specification (high condition).

---

[8] For this case study, measurements were made using an ATOS system, output to an STL file, and then summarized using PolyWorks software.

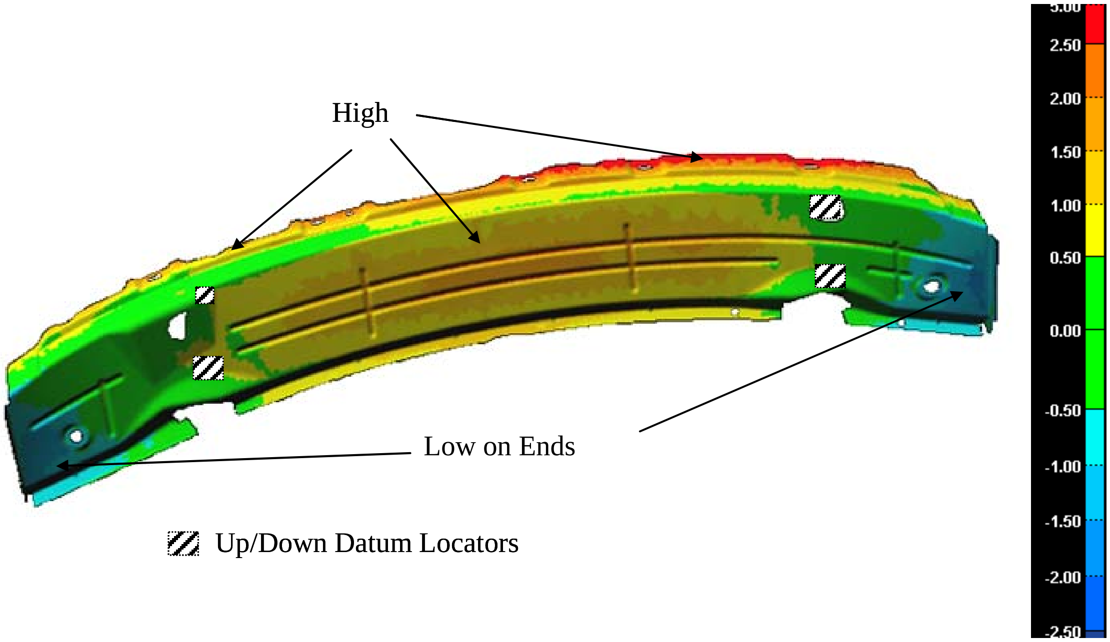


Figure 7. Cowl Case Study Measurements (First Panel Dimensional Review)

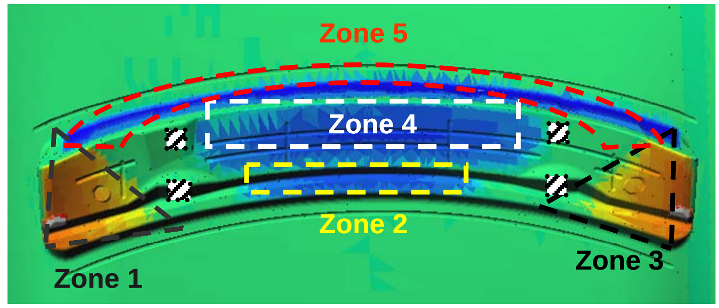
(Note: Green +/- 0.5; Light/Dark Blue -0.5 ~ -2; Yellow/Orange ~+0.5 ~ +2)

For this particular case study, the significant rework changes occurred in the draw die. Figure 8 shows the major rework areas and further classifies them into five zones. This figure shows a delta color map of the initial die condition[9] versus the rework compensation model. As may be observed comparing the delta die map and the initial finished panel condition, the draw die was morphed opposite the finished panel, but equal in magnitude (i.e., a 1:1 move). Since the original die was cut to product design, this delta map also represents the final die compensation model relative to product. In other words, to get the product near nominal, the die was under-compensated relative to product CAD up to ~2 mm in the center and over-compensated up to 1.5 mm on the ends.

[9] Initial die condition is the same as the product CAD.

Delta Map:
Die Rework vs. Die Initial

Green – no change
Yellow/Orange ~ 0.5 to 1 mm up
Light/Dark Blue ~ 1 to 2 mm down



Up/Down Datum Locators

Figure 8. Cowl Rework Areas (Reworked Draw Die vs. Initial)

Figure 9 shows the resultant panel after rework. The dimensional changes are further summarized in Table 7. Here, we may observe that the rework loop increased the percentage of the 3DNC inspection points within +/- 0.5 mm from 15% to 77%. In addition, the dimensions with deviations outside +/- 1 mm were reduced from 49% to 5%.

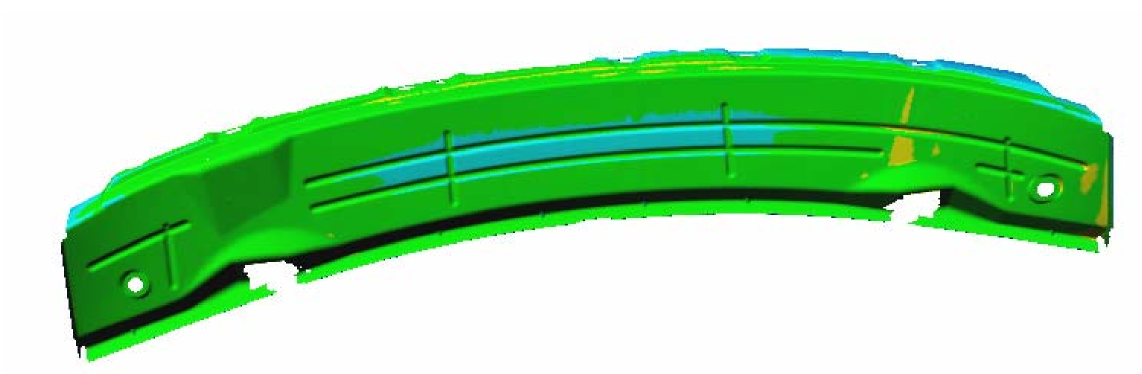


Figure 9. Finished Panel after Rework

Table 7. Measurements before and after Rework Loop

	Before Rework	After Rework
Total Points	265	265
Within +/- 0.5	39	203
Within +/- 0.7	78	246
Within +/- 1	135	251
> +/- 1	130	14
% Within +/- 0.5	15%	77%
% Within +/- 0.7	29%	93%
% Within +/- 1	51%	95%
% > 1	49%	5%

5.2 Rework Analysis by Zone

We now analyze the specific rework moves by zone. In general, most of the rework was based on 1:1 compensation moves. In other words, draw die surfaces for dimensional surface points were moved equal in magnitude but opposite in direction as the resultant initial finished panel. The following figures show the dimensional changes for each zone. The pictorials show discrete point measurements at common points for the initial draw die, the die after rework, the finished panel before rework, and the finished panel after rework. Measurements were taken at approximately 25 mm cross-sectional intervals along the Y direction (cross-car).

Figure 10 shows that for zone 1, the dies were reworked by stretching the ends equal in magnitude but opposite in direction as the finished panel-before rework measurements. This move resulted in shifting the points in this zone into specification (i.e., within 0.5 mm of nominal). A similar move and result was observed in zone 3 (mirror condition but on the other end of the part).

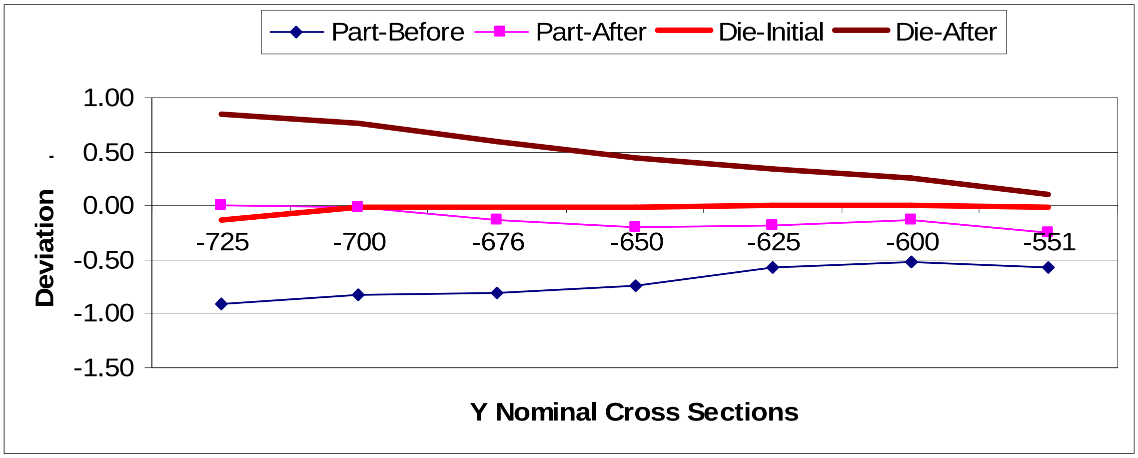


Figure 10. Zone 1 Changes

For Zone 2 (see Figure 11), the initial panel was approximately 1 mm high. Of note, for the region beyond +/- Y=300, the panel is moving toward nominal as the cross-sectional dimensions approach the location of the datum points. To improve zone 2 dimensions, the middle was stretched in the center equal in magnitude, but opposite in direction, as the initial finished panel. Again, the resultant part shifted near nominal. Here, the final draw die compensation required approximately a 1 mm under-cut for the part to spring into proper position in its finished state.

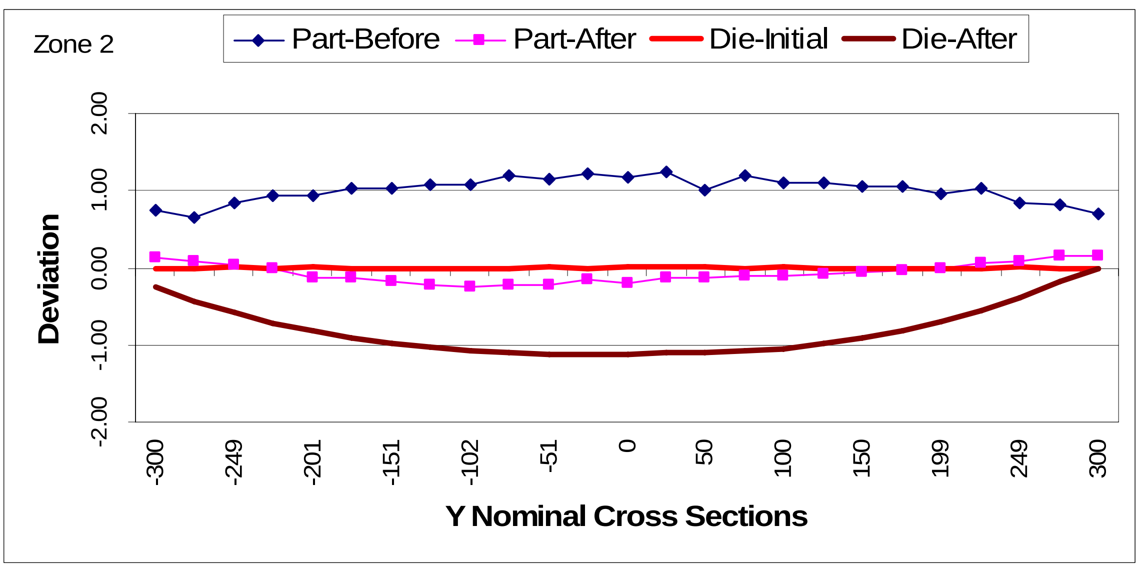


Figure 11. Zone 2 Changes

For zone 4 (the top, center surface of the part), a similar 1:1 compensation strategy was applied (see Figure 12). In this case, however, the die move resulted in a slightly higher part change than desired. Here, the part-die change ratio was 1.2:1. In other words, the part moved 1.2 units (1.2 mm) per 1 unit (1 mm) change in the die. In this case, the part did not spring back in the middle as much as predicted by the die compensation move. The resultant part deviation was still sufficiently close to nominal to not adversely affect the next-level assembly process and thus this condition was ultimately accepted.

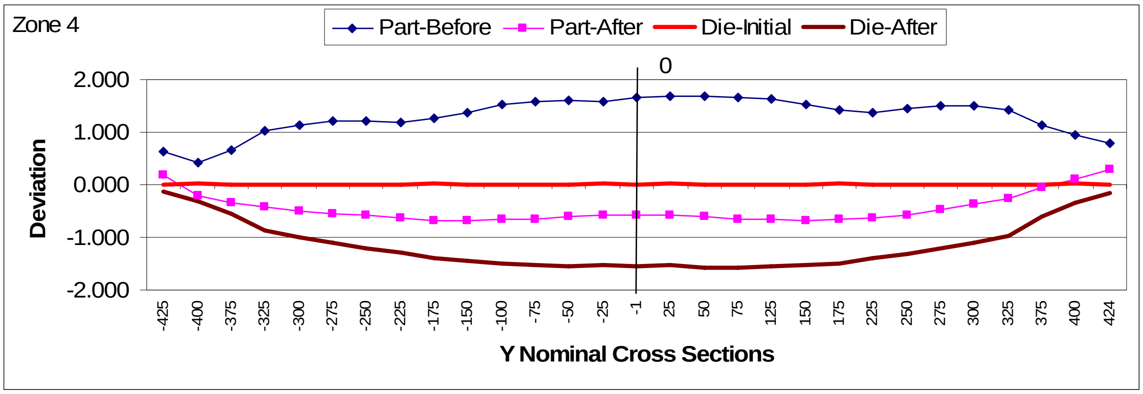


Figure 12. Zone 4 Changes

The most complicated rework move for this part occurred in zone 5 (see Figure 13 for an extraction of the part area versus CAD before rework). Here, to counter these part deviations, changes were made to stretch the flange in both X and Z directions. In addition, the magnitude of the deviations on right side (+Y) was larger than on the left side (-Y).

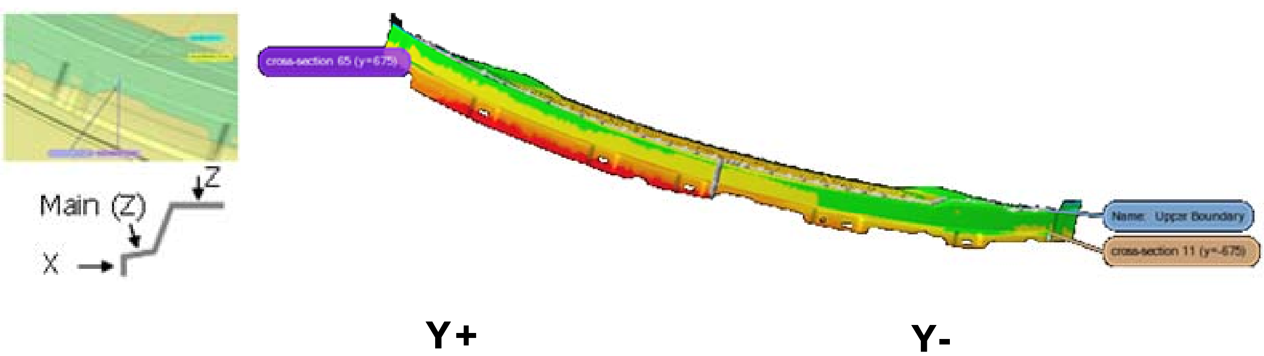


Figure 13. Zone 5 before Rework

Figure 14 summarizes these moves in both the X and Z directions before and after rework. The X was stretched 1:1; however, the Z-top measurements were reworked only half the magnitude in the die as the initial panel deviation. Of note, the left cross-sectional measurements (-Y sections in the figure below) were almost twice as forward (relative to car position) as the right-side measurements (+Y). In this +Y area, several dimensions remained out of specification, although the panel was shifted closer to nominal than before. These out-of-specification conditions were deemed allowable for the next assembly build operation.

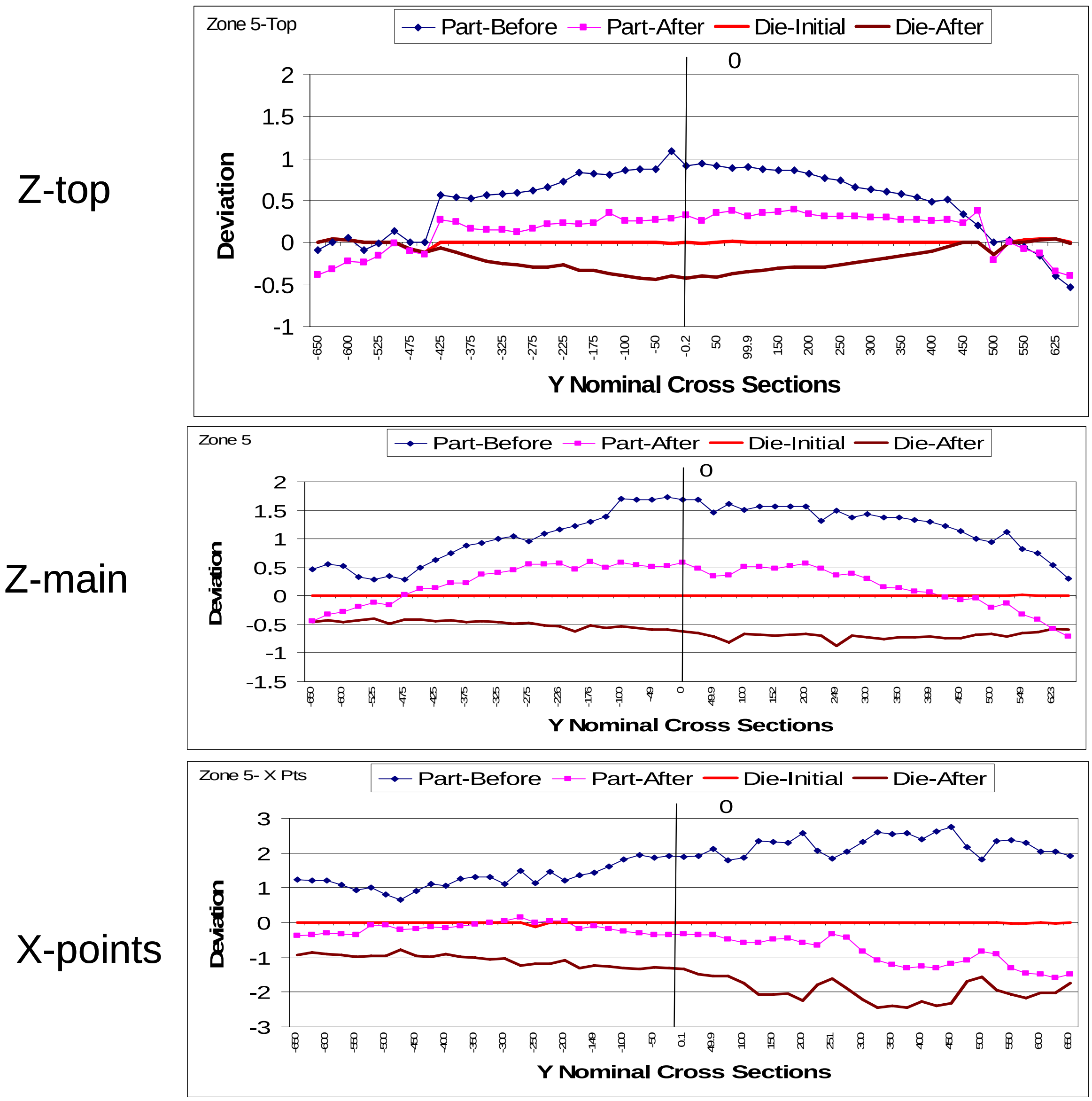


Figure 14. Zone 5 Die and Part Changes

Since zone 5 represents a combination move, we further analyzed the cross-sectional measurement points by examining the *area* change of the morphed die (before/after rework) versus the resultant change in the part area for each cross-sectional measurement. To do so, we established a boundary sample, created cross-sectional polylines, and then filled them in to obtain cross-sectional area calculations (Figure 15).

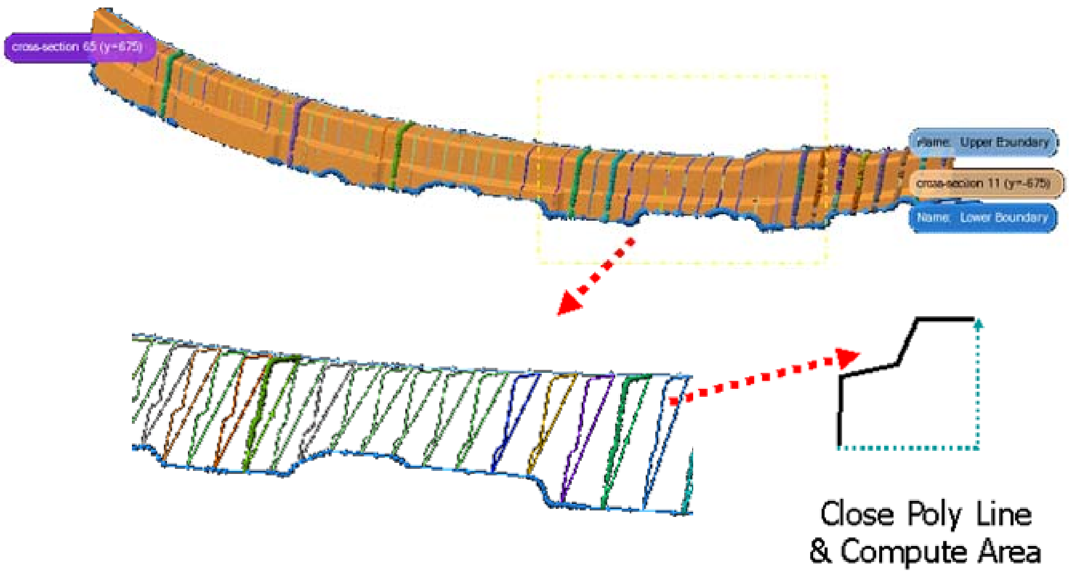


Figure 15. Cross-Sections from Boundary Area Used for Creating Polylines/ Areas

Interestingly, the part-die area ratio was larger on the +Y cross sections where the magnitude of the die area change was greater. This coincided with the fact that +Y sections exhibited greater deviations in the initial part measurements.

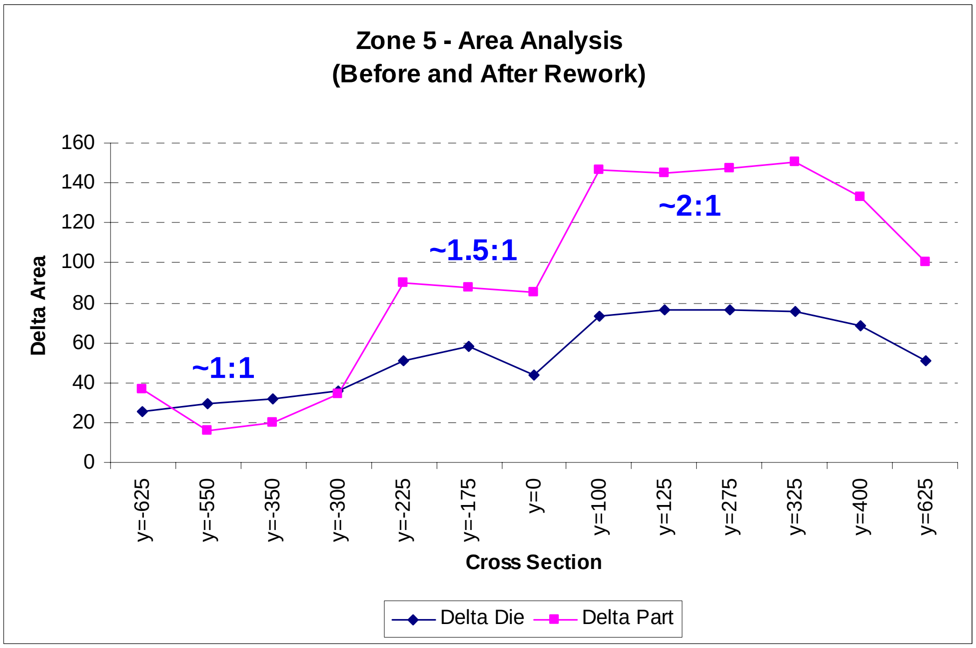
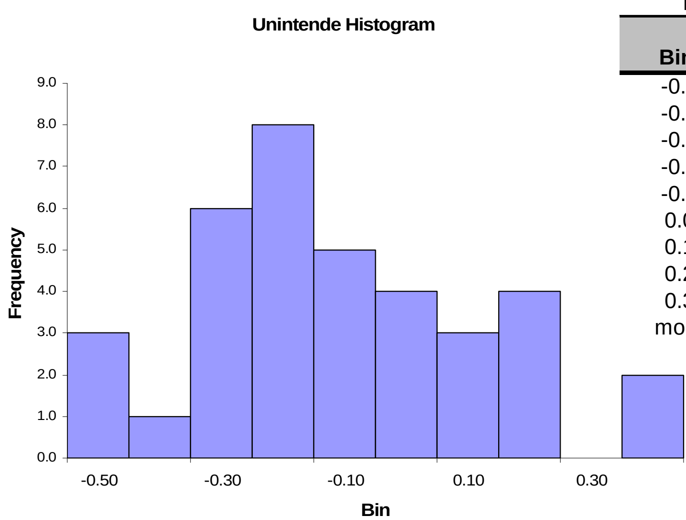


Figure 16. Cross Sections from Boundary Area Used for Creating Polylines/Areas

In addition to examining the effectiveness of these die compensation rework moves, we also examined unintended consequences. We did this by examining those dimensions in areas of the die that were not changed. Reducing die tryout rework iterations involves minimizing adverse dimensional changes in non-rework areas as well as fixing the problem areas. For this case study, the rework moves based on 3DNC measurement were made without any significant unintended consequences. Figure 17 summarizes minor unintended consequences of this rework.



Total: 36

Bin	Frequency	Relative Frequency	Cumulative Frequency
-0.5	3	8.33%	8.33%
-0.4	1	2.78%	11.11%
-0.3	6	16.67%	27.78%
-0.2	8	22.22%	50.00%
-0.1	5	13.89%	63.89%
0.0	4	11.11%	75.00%
0.1	3	8.33%	83.33%
0.2	4	11.11%	94.44%
0.3	0	0.00%	94.44%
more	2	5.56%	100.00%

Figure 17. Unintended Consequences

In this case study, the unintended consequences represented shifts of less than +/- 0.3 mm for ~80% of the dimensions that were not in rework areas. This coincides with typical levels of inherent variation in a stamping process.

Table 8 summarizes the before and after rework effect for part dimensions in both the intended and unintended rework areas. Overall, the dimensional concern areas were successfully reworked close to nominal and the unintended areas did not significantly change.

Table 8. Dimensional Changes: Intended and Unintended

Cowl Top	Before Rework (intended)		After Rework (intended)		Before Rework (Unintended)		After Rework (Unintended)		Before %	After %
N (points)	229		229		36		36		265	265
|Dev| < 0.5	17	7%	167	73%	22	61%	36	100%	15% →	77%
|Dev| 0.5 - 1	82	36%	48	21%	14	39%	0	0%	36%	18%
|Dev| > 1	130	57%	14	6%	0	0%	0	0%	49% →	5%
		100%		100%		100%		100%		

This case study demonstrates the effective application of 3D non-contact measurement to support die tryout. Of importance, the physical changes in the dies after rework had predictable, corresponding effects on the final part dimensions in the key areas of interest with relatively minimal unintended consequences. Using the 3DNC die tryout business process to identify rework opportunities and generate representative part data, the die expert was able to develop a die compensation model requiring only one significant rework iteration. Although this report shows only one case study, several others have used this same process and achieved similar results.

6. Conclusions and Future Research

This report provided a summary of several automotive body die tryout buyoff criteria, rework processes, and 3D non-contact measurement strategies. Relative to historical die tryout performance levels, a significant reduction in the number of iterations is clearly achievable through the following:

- Improved ability to create die compensation models to create new machine files to rework parts closer to nominal without significant unintended consequences. (Note: requires improved part measurement capability from 3DNC systems).
- Changes to existing die and production source part approval processes to make better decisions about when rework is needed to produce a dimensionally acceptable body.

Related to these improvements is the need for an effective business process integrating 3DNC measurement with new part approval processes to help manufacturers reduce the number of die rework iterations. A cowl top case study was used to demonstrate the application of this process. This case study involved the effective use of 3DNC measurement to reduce the number of tryout iterations to only one rework loop.

Additional case studies are needed to further evaluate the potential benefits of this process and to more comprehensively assess the ability to physically rework dies to desired dimensional magnitudes without adversely affecting other critical part dimensions. This will be the subject of subsequent reports.

References

1. *Production Part Approval Process*. Reference Manual. 3rd Edition. Automotive Industry Action Group, 2002.
2. Hammett, P.C. & Garcia Guzman, L. (2006). “White Light Measurement: A catalyst for change in automotive body Dimensional validation: Measurement Strategies for Stamping and Body Assembly from Tryout through PPAP”, UMTRI Technical Report 2006-3, January, 2006.
3. Hammett, P.C., Garcia-Guzman, L. and Geddes, S. (2007). “Improving Die Rework Capability: Opportunities for Using 3D Non-Contact Measurement Technology to Reduce Die Tryout Iterations to Resolve Dimensional Issues, Report for NIST-ATP.
4. Hammett P.C., Wahl, S.M., and Baron, J.S. (1999). "Using Flexible Criteria to Improve Manufacturing Validation During Product Development", *Concurrent Engineering: Research and Application (CERA)*.