Coherix®
3940 Ranchero Drive Ann Arbor, MI 48108-2775
734-761-8989 Fax 734-761-9193 www.coherix.com

White Paper
Accelerating United States Automotive Manufacturing Innovation
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Introduction
The global competitive marketplace for complex products, especially those with significant technical content such as automobiles and other vehicles, is highly dynamic and demanding. Market share is "king". End-user (consumer) demands are driven by changing economic conditions. Engineering requirements are driven by changing regulatory requirements, changing global economic factors, and changing experiences regarding fielded product recalls and warranty costs. Manufacturing requirements are driven by newly encountered production spill causes, supplier failures, and fielded product issues. In the face of this "sea of changes", the agility of manufacturers in their combined engineering and manufacturing processes is a critical determinant of their competitive posture, their market share and their ultimate survival.

This white paper focuses upon the specific need for agility in automotive manufacturing that must be manifested in acceleration of the manufacturing innovation cycle. However the same factors and considerations pertain to other manufacturing sectors ranging from household appliances to state-of-the-art electronic products, heavy industrial equipment, and aerospace systems. A few such sectors, such as aerospace/defense, have traditionally received more attention regarding acceleration of innovation via heavy investment and demands of the federal government as the primary "consumer". The automotive sector has not been similarly driven by its relatively unorganized end-use customer population.

A very specific enabling concept for achieving faster manufacturing innovation is addressed in this white paper. That is the need for, and the benefits achievable from, dynamic quantitative and comprehensive feedback of actual manufacturing process capability to product engineering function in an automotive manufacturing organization. The following sections will delineate the current general situation, discuss what could be achieved and how to initially demonstrate and prove the benefits that are achievable from implementing such a concept.

Situation Analysis Summary
Today the typical time-to-market for a new vehicle (passenger car, truck, SUV, etc.) is 3 years. This is the elapsed time from the start of a new specific vehicle model's engineering, after a "new vehicle concept" has been laid out, to the point at which the first actual production vehicle rolls off of the line to be delivered to a consumer. Many factors lead to this long time-to-market and this white paper does not address nearly all of them. Specifically the extended periods involved in satisfying the regulatory requirements for safety testing, etc. are not addressed.

The specific focus of this discussion is on actively closing the loop between a precision manufacturing process step and the engineering of the product component(s) that will be formed (machined or otherwise changed) or assembled in that process step.

At present, there is little if any direct, timely or quantitative communication from the manufacturing plant floor to the product engineering functions concerning how closely a designed product is actually being made relative to its specific design parameters. As a result:

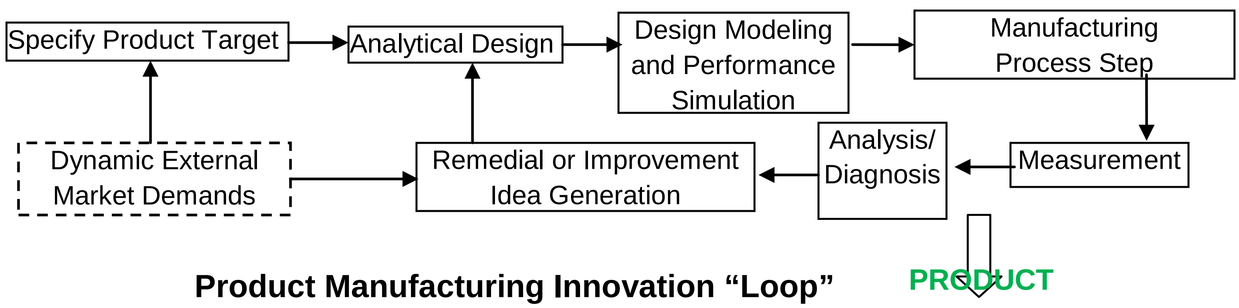
- The product component or assembly may be made such that it substantially more than meets design specifications in one or more specific senses.
- The product component or assembly may be made such that it does not meet one or more design specifications but is found by the manufacturing operation to adequately survive product tests.
- The product component or assembly may or may not achieve the performance that it could achieve with minor design changes
- The product component or assembly may cost more than it could cost and still be able meet performance objectives.
- Other discrepancies may also exist between the engineering expectations and the manufacturing perceptions of the manufactured part.

In short, the deviations between the "as-designed" product component or assembly and the "as-built" component or assembly are essentially not known to product engineering. Therefore the impact of the deviations on product performance, cost, and other important factors certainly cannot be known. The ultimate result is that opportunities to improve products through innovations in either cost or performance or manufacturability or any other factors largely do not exist.

An Opportunity for Acceleration of Manufacturing Innovation
A significant opportunity exists for accelerating the manufacturing innovation for a complex and diverse class of products. This opportunity is to create the timely and comprehensive feedback of data concerning each manufacturing process step, and the

results of each such step, to the engineering function for timely and efficient use in achieving innovative improvements in the product and, indirectly through its engineering innovations, upon the effectiveness of the manufacturing process.

This statement, while so self-evident as to encourage its dismissal, is nevertheless a fundamental need: If the combined engineering-manufacturing innovation cycle can be closed with sufficient information resolution, quality and quantity, then the manufacturer can approach the ideal of delivering products that are “rapid and right” with greater agility, flexibility and economy of its entire operations. The stages involved in this closed engineering-manufacturing “loop” can then be somewhat simply illustrated as:



Product Manufacturing Innovation “Loop”

Benefits of Manufacturing-to-Engineering Feedback

Specific benefits of achieving the suggested engineering-manufacturing loop have been demonstrated repeatedly in occasional *ad hoc* experiences in the industry. These benefits often go largely un-reported due to proprietary or other considerations. Among the benefits are the abilities to:

- Feed process measurements back to the engineering database so as to guide future designs
- Analyze the effects of manufacturing capability on product performance.
- Clarify product specifications
- Diagnose downstream product deficiencies
- Shorten the design cycle for future products or product corrections or other changes
- Reduce manufacturing costs caused by over-specification
- Understand the relationships among manufacturing variables and design variables. e.g., how does tool age affect ability to meet a specification?
- Lower product component costs by knowing how precisely the product can actually be made

With few if any exceptions, the integration of these tools has not become institutionalized as a routine practice. The result is major information gaps, severe limitation of the utility of the information that is produced, a lack of confidence in the credibility of that information, and the absence of the comprehensive information that engineering and manufacturing personnel could use to shorten the manufacturing innovation cycle for their products.

What Could be Created

It is suggested that a modest but realistic pilot program could accomplish a great deal in demonstrating by example to the entire United States “heavy industrial” manufacturing sector the benefits summarized above in comprehensively and tightly closing the manufacturing-to-engineering information path. Such an initiative is a perfect example of one that would be “transformational”, would meet a compelling national need (for global manufacturing competitiveness), and could be accomplished by the federal government taking the initiative to motivate its accomplishment.

A typical automotive manufacturing process step will be used as an example for discussion purposes in this whitepaper. Any of a wide variety of other manufacturing process steps could serve equally as well.

The precision machining of certain automotive parts – for powertrains, “car corner” parts such as braking system components, or other precision smaller components usually involves multiple stages of Computer Numerical Control (CNC) machines that remove material and create surfaces with various geometric features located in or on them. A typical CNC machine tool, such as a milling machine has some set of controllable parameters and some set of non-controlled characteristics (such as the current condition of the cutting tools). The usual ultimate result of a sequence of machining operations (process steps) is a finished part.

To completely characterize the manufacturing capability and operation of such a process step at any point in time, it would be necessary to measure the condition of the machine (both its controlled and its uncontrolled characteristics), the condition of parts entering the process step, and the condition of the parts exiting the process step. In general that would entail flexible metrology (sensing and processing) systems to measure all relevant current attributes of the parts which the process step might affect, as well as other instrumentation to measure the current uncontrolled characteristics of the CNC machine itself.

If such data were transmitted continually to the engineering function that was responsible for the design of the specific part being processed by that manufacturing step (CNC machine), then the engineering function would be able to utilize that data to achieve all of the benefits previously enumerated and almost certainly other benefits yet to be recognized.

A pilot program to provide a demonstration of this type would of course best involve:

- A part manufacturer and its engineering function (group),
- The appropriate CNC machine supplier's engineering function,
- A sufficiently comprehensive and flexible metrology technology suite, and
- The communications/software capabilities necessary to close the manufacturing-to-engineering data paths of the closed innovation loop that is to be demonstrated.

The key output of such a program should be the public dissemination of information describing in depth the demonstration and its beneficial results. The program could be conducted in an actual manufacturing plant setting or, if that is seen as being too distracting, could be conducted in a small surrogate manufacturing facility. But actual participation by representatives of an automotive manufacturer's or tier 1 supplier's engineering and manufacturing teams would be highly desirable to ensure that the "real-world" perspective of such automotive experts is obtained and documented and that they directly obtain and observe the benefits produced in the pilot operation.

Potential Types of Collaborators

While this white paper (as required) is NOT proposing any specific program, it seems warranted to suggest how the roles of government, high-technology organizations and U.S. domestic manufacturing industry could contribute their different areas of expertise in this suggested step toward improving the speed of U.S. manufacturing innovation:

- The obvious strong relevance of the project to meeting a national competitiveness and economic need suggests that the mission and expertise of NIST would be valuable to guide and review this enhancement of the national technology base.
- The specific relevance of the information produced by such a pilot demonstration indicates that appropriate suppliers of the software and CAD systems that are used by the manufacturer should be involved in the development and conduct of the demonstration project.
- An automotive part manufacturer should be motivated to play a significant role as a means to upgrading their manufacturing innovation "agility".
- A progressive CNC machine supplier should participate in the definition of the machine information to be gathered and fed back to the engineering database.
- A high-technology company engaged in providing flexible measurement technology to support advanced digital manufacturing methods may be the most effective leader for the project team in defining the details of the specific demonstration project, including the output information to be gathered and delivered to the manufacturer's engineering function.