UNITED STATES AUTOMOTIVE MATERIALS PARTNERSHIP

A Consortium of the United States Council for Automotive Research
Nondestructive Evaluation Steering Committee

Strategic Plan for Nondestructive Evaluation Development in the North American Automotive Industry

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Cover Photo: Pictured is a modern use of Nondestructive Evaluation for ensuring paint quality in an automotive assembly plant. Each of the two robots visible in the photograph is equipped with a pair of ultrasonic PELT® (Pulse-Echo Layer-Thickness) gauges that simultaneously measure the thicknesses of up to five paint layers at up to 100 points on the vehicle. This automated system provides timely feedback control of spray-booth parameters to ensure quality and reduce materials cost.

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This document was prepared by the USAMP Nondestructive Evaluation Steering Committee whose members are George Harmon, DaimlerChrysler Corporation, 2005 Chair; Cameron Dasch, General Motors Corporation, 2006 Chair; William Charron, Ford Motor Company; George Mozurkewich, Ford Motor Company; James Quinn, General Motors Corporation, and James Prindiville, Lawrence Livermore National Laboratory, DOE liaison. Deborah Hopkins, Lawrence Berkeley National Laboratory, is the primary author of the text. Constance Philips, NCMS, provided editing assistance.

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Preface

This document reflects a consensus between representatives of the United States Department of Energy (DOE) and US automakers that greater use of nondestructive evaluation (NDE) in automotive manufacturing will advance achievement of energy and environmental goals while also improving production efficiency and reducing waste. The United States Automotive Materials Partnership (USAMP) specifically focuses on developing technologies and methodologies that enable production of affordable vehicles having a significant reduction in mass and increased recyclability that will match or surpass the quality and durability of today's vehicles. This partnership contributes directly to DOE FreedomCAR goals that include eliminating harmful emissions and use of foreign oil.

This document was prepared under the guidance of USAMP's NDE Steering Committee, chartered in 2005 to develop a coordinated long-term vision for the direction of collaborative NDE research and development that will meet the needs of high-volume automotive manufacturing. The committee focuses on non-competitive projects that are consistent with USAMP, FreedomCAR and United States Council for Automotive Research (USCAR) goals. The purpose of this report is to describe that long-term vision and to provide a framework that will help the DOE and Original Equipment Manufacturers (OEMs) identify and prioritize research needs.

The specific objectives of the NDE Strategic Plan presented here are to:

- Stimulate development of NDE tools that meet the stringent requirements of the automotive industry;
- Provide an informational resource for DOE, OEMs and NDE developers including national laboratories, universities and suppliers and
- Outline NDE Committee guidelines for prioritizing and selecting projects.

To help foster NDE development, a National Laboratory Working Group was formed to work closely with the NDE Steering Committee to identify qualified federal research partners and resources. In the near term, these two groups will work together to initiate new NDE projects that will help accelerate the introduction of new materials, processes and technologies designed to advance energy and environmental goals.

Executive Summary

The automotive industry is facing significant new challenges. The already difficult task of meeting rising customer expectations for performance, cost, and amenities, plus sharply rising fuel costs and the pressure to reduce our reliance on oil, are increasing the pressure for leapfrog improvements in fuel efficiency, reduced emissions, and improved recyclability. Competition is intensifying, forcing manufacturers to reduce development times and to contain costs. Meeting these challenges requires highly innovative solutions that are driving introduction of new materials, manufacturing processes, and vehicle technologies. The unprecedented variety of options being explored, together with compressed time frames for implementation are greatly increasing the challenges of high-volume manufacturing and the corresponding opportunities for nondestructive evaluation (NDE).

NDE is an important tool for ensuring reliability and durability, improving quality, and reducing costs by improving process feedback and decreasing dependence on destructive tests. NDE is, furthermore, an enabling technology for reducing vehicle weight. Lightweighting entails using new materials, using old materials in more demanding ways, and introducing new production processes for both new and old materials. In addition, vehicles incorporating a variety of materials encounter new joining issues. Each of these developments stretches current design approaches and production methods, introduces new sources of variation, and increases the need for NDE at one or more stages in the vehicle design and production cycle. Emerging challenges, such as fuel-cell vehicles and recycling, afford additional impetus for increased use of NDE.

Successful NDE technologies must be designed to work well in a high-volume production environment. Desirable characteristics include ease of use, including automation and built-in intelligence when appropriate; speed adequate to meet production rates; and robustness against harsh plant environments. Standards, calibration procedures, and inspection protocols must be developed. Modularity will prove beneficial. Gaps between today's NDE tools and those that need to be developed have been identified. Development paths are outlined providing direction for new advances in NDE technology.

Near-term NDE needs are currently greatest in body materials, chassis and powertrain components, and assemblies, which typically account for 80 percent or more of the total vehicle weight. These components include sheets, castings, and joints. For these, there is a strong driver for technologies which can facilitate introduction of materials or processes that contribute to lightweighting and have the likelihood of overcoming potential hurdles to implementation and adoption in high-volume manufacturing. Specifically, technologies that apply to more than one material, process or product are most beneficial, as are technologies that close one or more of the identified NDE gaps. Agile tools that can expedite engineering development and manufacturing ramp-up, in addition to ensuring quality in manufacturing, are also desirable.

The short-term payoffs from successful implementation and adoption of NDE technologies are greater use of lightweight materials, plus cost and energy savings derived from reduced waste and increased production efficiency. The long-term payoff is inspection integrated with process control that stands to greatly accelerate the introduction of new materials, processes and vehicle technologies.

Chapter 1. Introduction

Nondestructive evaluation (NDE) includes a broad spectrum of measurement and analysis tools that allow inspection and monitoring without damaging or altering the test specimen or part undergoing evaluation. In contrast, destructive testing, such as strength testing to failure or peeling apart welded joints to examine weld buttons, destroys the part under inspection and is not suitable for online applications. NDE techniques include everything from relatively simple dunk tank tests to find leaks and dye-penetrant methods used to identify surface cracks, to highly sophisticated mass spectrometry to find leaks and to electromagnetic, ultrasonic, thermographic and radiographic imaging techniques used to identify and characterize discrepancies[1] at and below the surface.

The field of nondestructive evaluation has its roots in aerospace and other high-risk industries such as nuclear power where failure could result in catastrophic loss. For this reason, inspection is mandated by government regulations, and to a large extent, these industries drove NDE development historically. Ideally, the automotive industry would be able to meet its needs by adopting technologies already used in traditional markets where NDE is well established. There are, however, fundamental differences between the automotive sector and industries like aerospace and power generation that limit the possibilities for meeting automotive needs through technology transfer. As a result, a tremendous challenge in increasing the use of NDE in the automotive industry is fostering a market that will respond to automotive needs.

The aerospace and power industries are characterized by long development and construction phases followed by even longer service lives. Their capital investments are huge, and operational safety and reliability must be ensured over service lives that last for decades. In sharp contrast, the development time for automobiles is 18-36 months, and shrinking, and the service life for automotive vehicles is approximately 10 years. Whereas a major commercial aircraft manufacturer may build and sell a few hundred units annually, U.S. auto manufacturers make millions of passenger vehicles per year with increasing market pressures to reduce production costs and increase production efficiencies. While the almost immeasurable cost of failure in aerospace and the nuclear power industry creates a business case justifying extremely expensive inspection programs and large investments in equipment and training, robust competition makes the auto industry extremely cost sensitive. This cost sensitivity creates a strong emphasis on increasing productivity and eliminating operations perceived as unnecessary.

Another significant difference between traditional NDE markets and the automotive sector is that cars are a consumer commodity, with customer satisfaction driving the market. While consumers will spend extra money for titanium and carbon-fiber composites in sports equipment, the sophisticated technology and high-tech devices in vehicles are largely hidden from view and are not well understood by the consumer who places high value on style, comfort and amenities. Rather than being marketable attributes, new materials in vehicles may be met with consumer uncertainty.

In addition to the difficult challenge of meeting customer expectations for performance, comfort and cost, automakers are facing significant new challenges. These challenges include increasing fuel efficiency, reducing harmful emissions and improving recyclability; at the same time that increasing competition is reducing development times and forcing manufacturers to look for new materials and processes allowing the production of cars faster, better and at lower cost. Adding to these challenges is the globalization of the automotive industry that has resulted in a rapidly expanding supplier base spread out across the globe, increasing the challenge of assuring the quality of supplier commodities.

Meeting these challenges requires highly innovative solutions, which are expanding the need for NDE in automotive manufacturing. There may be inherent conflicts in meeting some of these challenges simultaneously. For example, while lighter-weight vehicles support fuel efficiency, many lightweight materials are more difficult and costlier than steel to recycle today. Quality may be defined by consumers by factors such as reliability, durability, noise and vibration, with the latter leading to greater use of adhesives, whereas recycling is facilitated by easy disassembly of vehicles and is made

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[1] In this document the word “discrepancy” means any deviation from engineering specifications.

more complicated by adhesives. In these cases, the challenge is to find the optimal tradeoffs between competing objectives. NDE can enable designers and engineers to evaluate the tradeoffs between durability factors, fuel efficiency, quality and recyclability by providing the means to confirm that steps taken to address one objective have minimal impact on other objectives. Additionally, NDE can provide inspection techniques to ensure that a lightweight material or use of thinner gauges for example does not compromise performance or quality of a part.

Rapidly evolving technology is expanding the base of possible solutions to automotive challenges, while also advancing the development of NDE systems that meet the demanding requirements of the automotive industry. The down side is a proliferation of technical options that need to be explored and evaluated. For those solutions that appear most promising, manufacturability has to be determined. Typically before new materials and processes are introduced into high-volume production, the process is monitored to demonstrate reliability and repeatability, and the resulting product inspected to identify and characterize discrepancies introduced during manufacturing. Long-term process-monitoring and part-inspection needs depend on how well the manufacturing process can be controlled. Inspection is typically necessary for performance-critical and high-value-added parts, and to troubleshoot problems when processes go out of control.

Even with increasing benefits to be gained by inspection using NDE and the promise of emerging technologies that can meet the technical requirements of automotive applications, NDE will not be implemented without a strong business case. In manufacturing, the business case for NDE rests in part on its ability to decrease or replace destructive testing. Assemblies that are routinely subjected to destructive teardowns are scrapped. The cost of lost product from sales revenue is estimated to exceed a million dollars per year at typical production facilities. Replacing destructive tests with NDE results in cost savings from reduced scrap, reduced inspection times and a reduction in labor costs associated with the teardowns and ergonomic issues associated with physically demanding tasks. The optimal cost savings occur when NDE is used as far upstream in the manufacturing process as possible. When NDE is performed on line, there are potentially significant cost reductions from identifying and correcting problems as early in the production process as possible.

The most imminent automotive needs for NDE are associated with introducing new materials to make vehicles lighter. The plan presented here for advancing the use of NDE to meet these needs is based on having identified the gaps between NDE technology that is currently available and what is needed to meet the requirements of high-volume automotive manufacturing. The path put forth to bridge the gaps makes clear the research and development required. The consensus is that NDE is an important tool to be used in the automotive sector to ensure reliability, durability, improve quality and reduce costs. Developing and implementing those NDE tools required to enable greater use of lightweight, reclaimable materials, and new vehicle manufacturing and assembly technologies depends on closing the gaps between where NDE tools are today and where they need to be to accelerate introduction of new materials, new processes, and new products.

Chapter 2. The Expanding Role of NDE in the Automotive Industry

NDE plays a particularly important role whenever something new is introduced in the automotive industry, be it a new material, manufacturing process, vehicle technology, or a new product. NDE is valuable in process implementation and validation. For example, NDE helps in the identification and analysis of:

- Discrepancies introduced by a particular manufacturing or assembly process.
- Process controls needed.
- Part inspection requirements.

The challenges facing the automotive industry are driving introduction of new materials and production technologies to improve quality and reduce costs. In response to these drivers, the industry is using and exploring new processes such as

- laser welding and laser brazing,
- friction-stir and ultrasonic welding,
- adhesive bonding,
- die casting,
- wet-on-wet and powder-process paints and
- semi-solid forming.

Ever increasing demands for performance and quality, along with government initiatives, are resulting in a host of new products including everything from fuel cells to super capacitors. The introduction of these new materials and processes is coincident with advances in NDE technology, and together the two trends are creating significant new opportunities for NDE in the automotive industry. Industry's challenges and the corresponding NDE opportunities are summarized in Table 2.1.

Competitive pressures are also creating new inspection and monitoring needs. The lead time for vehicle development has gone from something like five to seven years in the past, to 18 to 36 months now. This greatly reduced development time puts tremendous pressure on researchers and engineers to make things work the first time. Instead of relying on several cycles of testing and redesign to reach performance targets, they now utilize more calculations and modeling. This creates some uncertainty during engineering and the ramp up to production, increasing the need for monitoring and inspection to ensure that engineering specifications are being met. Reduced lead time also means that there is less time to ensure that manufacturing processes are controlled to the degree necessary when new materials and processes are introduced. This means a greater need for NDE during production startup, and quite possibly on a long-term basis, to ensure product quality.

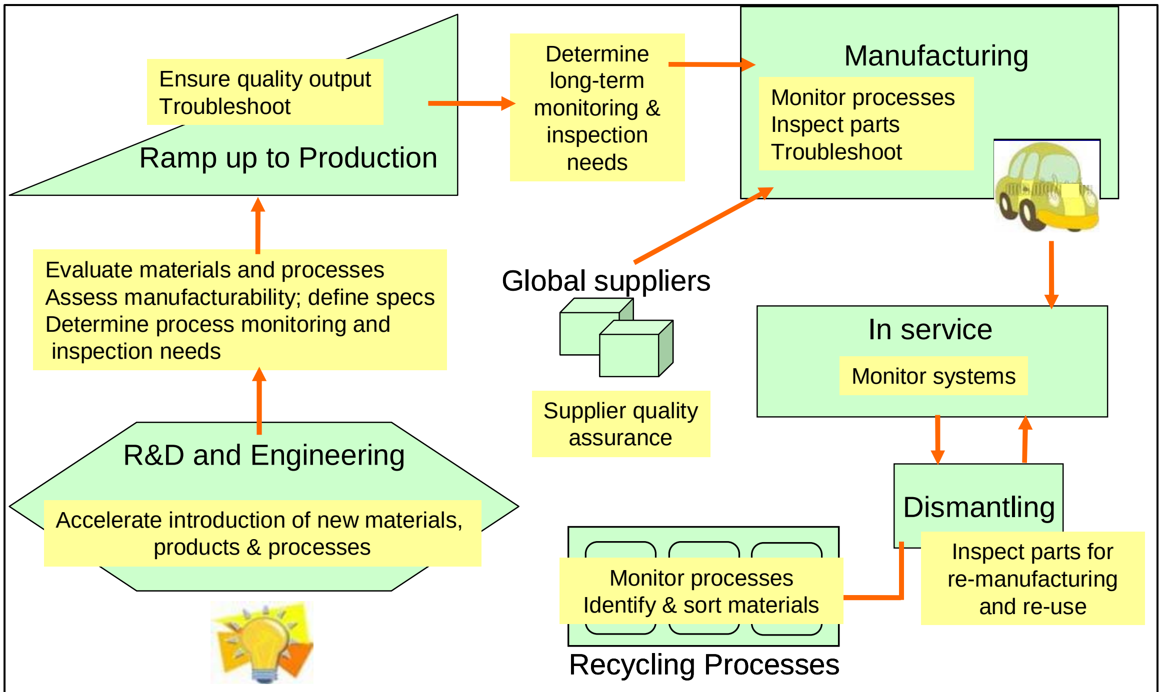
NDE is commonly used whenever it is needed to ensure part performance and quality, e.g. inspection of vital chassis components to verify part integrity. The most commonly used NDE method during manufacturing is leak testing. It is applied to a wide variety of components, including engines, transmissions, fuel systems, wheels and gas tanks to whole vehicles. Leak test methods vary from simple water-intrusion tests to laser-excited fluorescence to pin-point leak sources. Many of these processes are automated as part of the production line to provide 100 percent inspection. Another automotive success is the use of ultrasonic gauges to measure the thickness of paint, as shown in the Cover Photo. Up to five layers of paint are measured simultaneously with an accuracy of 1 micron. For case-hardened parts including cams, cam shafts, hubs and axles, both ultrasonic and eddy-current methods are used to measure the case depth. In addition to tests performed by OEMs, suppliers are often required to inspect their products. For example, eddy-current testing is typically required by OEMs for all welded tubing used in brake and fuel lines.

Besides inspection of components, NDE is used during manufacturing for process monitoring and for troubleshooting when things go wrong in production. For example, thermography is used for routine maintenance of controller electronics and to detect hot spots on machinery and excess heat from failing components. Radiography is a very important NDE diagnostic tool, for example, to image cracks and porosity. Relatively simple dye penetrant and magnetic-particle inspection methods are used to detect surface cracks, while ultrasonic and eddy-current techniques are used to find cracks in everything from pistons to cylinder bores and liners.

NDE techniques have the potential to contribute at all stages of the vehicle’s life cycle, from research and engineering, to manufacturing, in-service monitoring and recycling. The existing and potential roles of NDE at each stage are summarized in Figure 2.1 and detailed in Table 2.2. In addition to the uses of NDE during manufacturing discussed above, keeping vehicles affordable means reducing costs, including reducing waste and improving production efficiency. NDE stands to contribute in these areas by reducing destructive testing and providing better and faster feedback to processes. NDE is already used to inspect parts such as air bags that cannot be functionally tested, and once the vehicle leaves the factory floor, NDE has the potential to be used for in-service monitoring of these systems to prevent failures. When the vehicle reaches the end of its service life, NDE techniques are used in recycling to identify and sort materials, and may have a role to play in monitoring recycling processes and in evaluating the resulting products to maximize recovery and reuse.

Table 2.1 Industry Drivers and NDE Opportunities in Manufacturing

Manufacturing Challenges	NDE Opportunities
Industry Goal: Improve Fuel Efficiency	
Increasing use of lightweight materials. Use of thinner gauges.	Developing NDE techniques for new materials and joining methods. Ensuring quality and durability. Defining inspection specifications for new materials and processes.
Introducing new powertrains: • Hybrids • Fuel cells • Hydrogen powered.	Ensuring performance and durability; e.g., Inspecting fuel-cell seals, Detecting leaks. Inspecting components during manufacturing.
Introducing new energy storage devices: • Batteries • Hydrogen storage tanks.	In service: Monitoring state of charge, Monitoring tanks.
Industry Goal: Ensure Product Quality	
Ensuring customer satisfaction. Guaranteeing performance. Maximizing durability. Minimizing NVH.	Monitoring the application of adhesives and mastics. Inspecting joints.
Confirming supplier quality in a global economy.	Inspecting supplier parts to confirm that they meet specifications.
Ensuring quality during manufacturing.	Process monitoring. Troubleshooting problems.
Ensuring the integrity of components.	Providing faster and more reliable inspection of components during manufacturing.
Preventing part failures.	In-service monitoring of vehicle systems.
Industry Goal: Produce Affordable Vehicles	
Reducing the lead time for product development. Increased reliance on validation.	Filling the need for increased inspection during research and engineering. Reducing mechanical testing with NDE validation.
Increasing productivity.	Process monitoring and in-line inspection.
Adopting flexible manufacturing.	Enabling automated inspection.
Making more efficient use of materials. Reducing waste.	Providing agile inspection tools.
Improved ergonomics.	Reducing destructive testing.



Starting in the lower left-hand corner, the diagram illustrates the life cycle of a vehicle from research and engineering, through production, service and recycling. The yellow boxes indicate existing and potential roles of NDE at each stage.

Figure 2.1 Existing and Potential Roles of NDE at Each Stage of the Vehicle Life Cycle

Table 2.2 The Role of NDE in the Vehicle Life Cycle

The Role of NDE in the Vehicle Life Cycle	
R&D and Engineering	Accelerate introduction of new materials, processes, and products. Select sound parts for product validation. Define inspection requirements for materials and systems.
Ramp up to Production	Ensure that requirements and specs are met. Monitor and evaluate processes – determine how well the process can be controlled. Ensure quality output. Identify and evaluate discrepancies induced during processing. Troubleshoot problems. Determine long-term monitoring and inspection needs.
Manufacturing	Assure the quality of materials and components supplied by the rapidly expanding global supplier base. Inspect components that cannot be functionally tested; e.g., air bags. Monitor processes. Inspect output when processes cannot be controlled adequately and/or when the part is performance-critical or is a high-value-added part. Troubleshoot when something goes wrong. Quickly identify affected product.
In service	Inspect in-service components. Prevent system failures.
Recycling	Develop and apply NDE tools to enable remanufacture and reuse.

2.1. The Role of NDE in Lightweighting

Somewhere between 80 and 90 percent of the weight in a typical vehicle is in the body, chassis and powertrain. Substituting lightweight materials for steel and cast iron in these areas therefore provides the greatest impact on lightweighting. For this reason, industry has a particular interest in using lightweight materials for body panels the chassis and for castings used in powertrain components. Weight reduction is also being achieved through vehicle design and by using thinner-gauge materials. In general, lightweighting is best served by having a wide range of material and design options that allows use of material well suited for an application. While this strategy is optimal for weight reduction, the new designs and increasing number of materials create significant manufacturing challenges that are increasing the need for NDE.

Lightweight Materials

NDE is an enabling technology for greater use of lightweight materials in automotive applications because of the need to assure the reliability and quality of new products. New materials currently being introduced or under consideration include advanced high-strength steels, aluminum, magnesium, titanium, composites and ceramics. For new materials it is essential to demonstrate that performance, consistency and durability can be maintained during high-volume manufacturing. Here we use “new materials” to describe material not traditionally used in vehicles, such as magnesium, newly developed materials and alloys and familiar automotive materials used in new ways.

Along with new materials come new manufacturing processes. Even new alloys of steel present manufacturing challenges as do each of the many varieties of plastics, composites and ceramics. NDE is required to demonstrate the ability of these new and little-understood processes to reliably produce consistent, high-quality parts during high-volume manufacturing. Some of the manufacturing challenges arise from the lower intrinsic strength of lightweight materials compared to steel. This difference makes it necessary to more tightly control material properties throughout the structure, making it essential to identify, characterize and quantify discrepancies introduced during manufacturing for example:

- tears in sheets,
- porosity and oxide inclusions in castings and
- impact damage and non-uniform distribution of fibers in composites.

For ceramic materials, identifying even small flaws is important because they can be sites of crack initiation. Other manufacturing issues arise when lightweight metals are less amenable to traditional steel-based automotive processes. For example, lightweight metals are generally more difficult to form during stamping and have a tendency to “spring back.” NDE techniques for measuring residual stresses would find many applications, including those associated with forming.

Coatings

In concert with the introduction of new materials and powertrain components is increased use of coatings. Coatings enable greater use of lightweight materials by imparting properties required for automotive applications. One of the most vital uses is to ensure corrosion resistance. Coatings are also used to increase hardness and fatigue strength, improve wear resistance, provide sufficient heat resistance for high-temperature applications and reduce surface roughness and friction. For example, meeting the surface finish and roughness specifications for bearing surfaces is essential in achieving the performance required for moving parts, particularly for high-speed, high-stress and/or high-temperature applications. Coatings offer a solution for many materials where machining cannot achieve the required surface condition. Because coatings are used to assure properties in specific applications, there is a need for NDE to verify coating thickness and integrity.

Joining

Joining is almost always an issue when introducing new materials, and one of the significant technical challenges in increasing the use of lightweight materials is developing joining technologies and inspection strategies suitable for mass production. NDE is viewed as an enabler for lightweight materials in part because joints in some materials cannot be destructively tested. Whereas spot-welded joints in steel are routinely pry-checked (see Figure 2.3), and subjected to periodic, destructive body-in-white teardowns (see Figure 2.4), many lightweight materials and the methods used to join them are not amenable to destructive testing. For example, NDE is a necessity for spot-welded aluminum joints because they cannot be pry checked without damaging the joint. Further, destructive teardown to check such welds is expensive because of the high cost of scrapping aluminum. Similarly, continuous joints such as adhesive bonds or laser welds can be very difficult to destructively inspect, and joints in high-strength-steel can be too strong to be pried apart.

In addition, there is a need for NDE tools to inspect mechanical fasteners, including those being used to attach thin sheets to castings and joints welded using new methods such as friction-stir and laser welding. Even though the auto industry has decades of experience with traditional welding, it can be difficult to completely control these new processes, and it is not uncommon to see discrepancies that have not been seen before. Meanwhile, new joining methods also introduce new process-control issues. For example, adhesive bonding requires NDE techniques to confirm the right component mix, correct placement, adhesion, and proper cure of the adhesive. As discussed in the following section, design trends driven by lightweighting are also impacting joining methods. For example, if space-frame construction is adopted as a weight-saving measure, it is likely that new fastening and joining methods will be employed, which will likely present new manufacturing and inspection challenges.

Designing for Reduced Weight

Over the past three decades, the mandate to reduce vehicle weight has led to design changes such as moving away from traditional body-on-frame constructions toward unibody designs. Virtually all mass-produced vehicles today are based on unibody construction. “Unibody” is something of a misnomer in the sense that unibodies are composed of many different parts that are spot welded together. In contrast to body-on-frame construction, the unibody is designed to bear load and to provide structural rigidity, making it more important to ensure the integrity of the joints in the body. When using thinner gauge materials to save weight, a problem that arises during production is their susceptibility to tearing, increasing inspection needs compared to those required for thicker sheets. Thinner gauges also leave less margin for error and may require increased inspection during manufacturing to ensure that engineering specifications are being met.

To simultaneously reduce weight and maintain or improve reliability and quality, it becomes increasingly important for designers and engineers to have a variety of materials at their disposal and the freedom to put the right material exactly where it is needed. This increasing complexity greatly increases manufacturing challenges and the need for process monitoring and inspection. For example, new processes are being developed to join dissimilar materials. In addition, at all stages of manufacturing, corrosion is an issue, and the growing trend to use dissimilar metals in close proximity exacerbates the problem, creating a need for NDE methods that can detect corrosion. The need to put the right material exactly where it is needed is driving the trend to increasingly use tailor-welded blanks. The technique of welding blanks was developed to allow different steels to be used in a single blank, thus allowing designers and engineers to vary material properties according to need. Now, a new trend to join different gauge materials in tailor-welded blanks further increases the inspection challenge of verifying the quality of the welded joint.

Although it is very difficult to predict the material and design choices that will be made in the future to reduce vehicle weight, it can be assumed that there will be increased use of new alloys of steel and lightweight materials. It can also be assumed that vehicle designs and material specifications will become more complex, to allow the flexibility necessary to better match material properties to required performance at specific locations. The expanding choice of materials and more flexible designs stand to greatly contribute to lightweighting. However, at the same time, both trends face substantial manufacturing hurdles, and the new processes required will demand new NDE technologies.

2.2. The Role of NDE in Manufacturing

Process control is an imperative in the auto industry to ensure quality and to avoid exorbitant costs incurred when a production line has to be shut down. It is therefore essential that processes and machinery be maintained and monitored to the degree possible to prevent equipment failure, to catch problems as early as possible and to ensure the quality of the resulting product.

In a perfect manufacturing world, processes would be controlled closely enough to ensure the quality of the product at all times. When the process cannot be controlled adequately, the alternative is to inspect 100 percent of the resulting product. Statistical process control is a sampling-based methodology that aims to identify and eliminate variance in the production process. The business case for setting the frequency of inspection depends on the value added by the process and how important the product is to vehicle quality. When problems arise, NDE methods can be employed to help troubleshoot the problem, for example, using thermography to find hot spots on machinery, or using NDE to quickly identify the affected product. The fact that certain inspections are not performed on a daily basis does not minimize their importance for maintaining quality – it is essential to be able to troubleshoot and quickly determine exactly where the process has gone out of control.

Figure 2.2 illustrates the relative need for NDE during product development and implementation for six different scenarios. In general, the need for NDE is greatest during engineering and the ramp up to production. The first scenario represents the least challenging case. As indicated by the red line, when a traditional material is used with a familiar process, minimal NDE is required during engineering and ramp up to ensure that technical targets are met. During production, the NDE required depends on how well the process can be controlled, as well as the value added and the specification requirements for the part. A well-controlled process for a low-value-added part requires minimal if any NDE, as indicated in the first scenario. The second scenario illustrates what happens when a process goes out of control. The expense of shutting down a production line makes it imperative to find the problem and identify the affected product as quickly as possible. Whether or not the required NDE returns to the lower level indicated by the red-dotted line depends on how well the process can be brought back under control.

Scenarios three through six illustrate a variety of cases for materials or products that require new processes. If the material is also new, a relatively high level of NDE is required during engineering and the ramp up to production to assure performance. Composites are an example of a relatively complex material, in which it can be difficult to ensure consistency. The ramp up to engineering is most challenging when the process is new and complex and/or new tooling is required. In these cases, NDE is essential to determine how well the process can be controlled and to identify and characterize discrepancies introduced during processing.

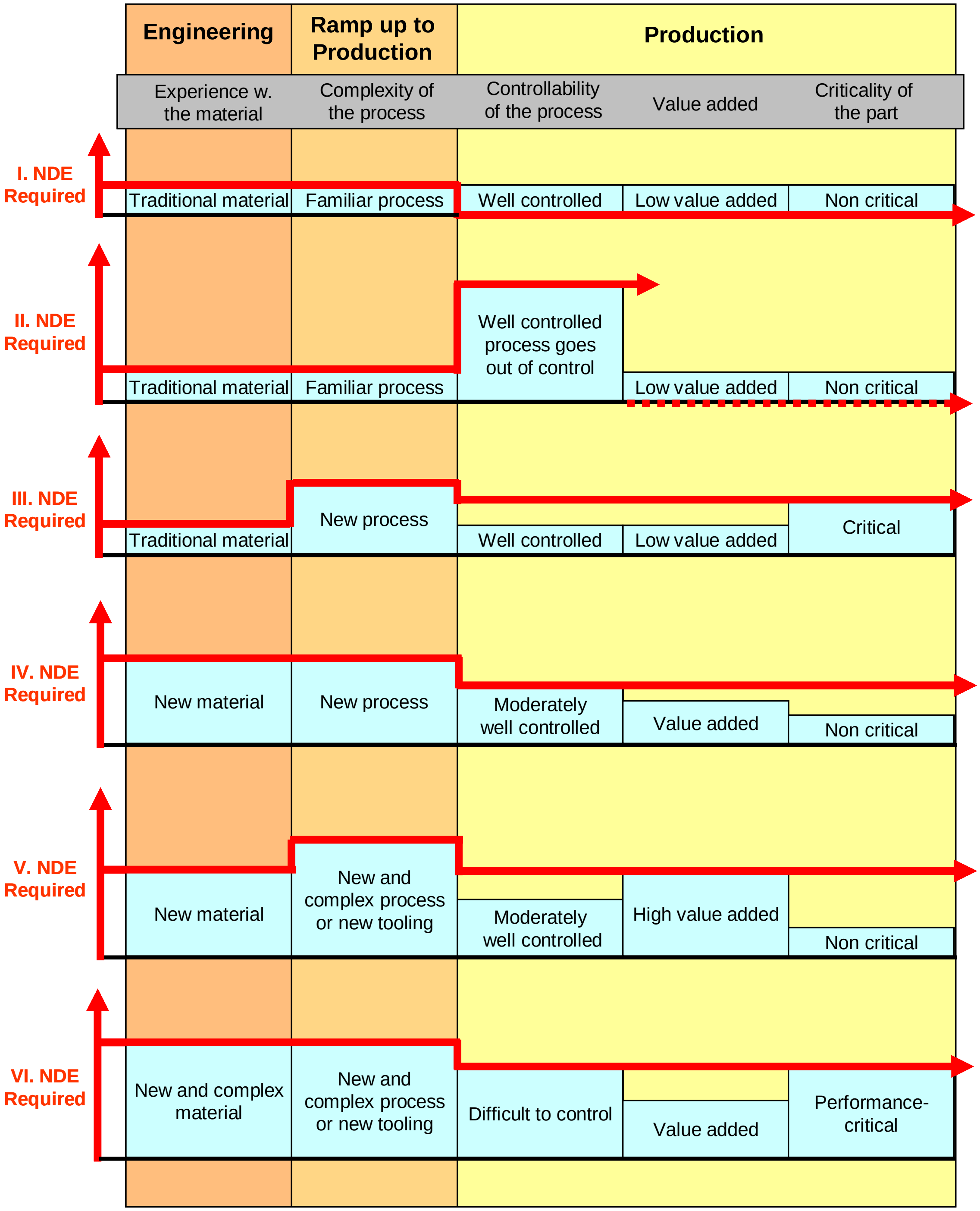


Figure 2.2 The Relative Need for NDE from Engineering through Production

The horizontal red lines illustrate the relative need for NDE during product development and implementation for six different scenarios. In general, the required NDE is highest for new materials and processes, and for performance-critical and high-value-added parts.

Potential Benefits from Increased Use of NDE in Manufacturing

NDE has the potential to reduce manufacturing costs by decreasing destructive testing and improving process feedback. Cost savings are greatest when NDE is used as far upstream in the process as possible, arguing for online inspection. In this case, discrepancies are identified as early as possible and there is immediate feedback to the process. The cost effectiveness of online NDE depends on the value added by the process and its complexity compared to the cost of the NDE system including installation, training and maintenance costs. The higher the value added by the process, the more costly it is when unsatisfactory parts are produced or when the process is applied to already discrepant parts. The NDE techniques that are currently used online tend to be low-volume, high-value-added processes that can be monitored using inexpensive sensors. Although it is perhaps counter intuitive, the business case for high-volume applications can be difficult to make. For example, several welding robots may be used to weld a single subassembly meaning that adding an inspection capability requires retrofitting each robot. The required capital expense may be too expensive, particularly if problems are infrequent.

In addition to being cost effective, to be successfully adopted in plants, NDE cannot interfere with production. Although this need also argues for in-line inspection and automated processes, there is a chicken-and-egg problem: fully automated systems will most likely be judged cost-adverse until successful in-plant installations demonstrate that the systems are cost effective and robust enough for production facilities. This means that in the near-term, NDE is likely to be used off line. However, even if not fully automated, off-line inspection can still bestow cost benefits by decreasing or eliminating destructive testing and providing better process feedback.

An example: spot-weld inspection

Destructive teardowns of spot-welded assemblies are performed during each shift and full body-in-white teardowns are performed periodically to check the quality of spot welds (see Figure 2.4). These inspections are labor intensive, physically challenging, and time consuming. The cost of labor and the scrapped material is substantial, and when discrepancies are found, the time lag between when the problem first occurred and when it was discovered can result in significant costs because of the need to quarantine and check large numbers of assemblies. Nondestructive ultrasonic weld inspection holds the promise of greatly reducing the need for destructive teardown, reducing scrap and labor costs, while at the same time providing faster and better feedback to welding processes.

Figure 2.3 Pry checks are routinely performed on spot-welded steel assemblies to ensure the quality of the welds.

Figure 2.4 Full body-in-white teardowns are performed periodically, during which every welded joint is pried apart to examine and measure the resulting weld buttons.

Photos courtesy of Ford Motor Company

2.3. Emerging Challenges

Cars are arguably the most complicated consumer product on the market, and the innovative solutions required to meet emerging challenges will make them increasingly complex. For example, sharply rising fuel costs and the mandate to reduce our reliance on foreign oil are already increasing pressure for leapfrog improvements in fuel efficiency. At the same time, environmental concerns are driving efforts to improve recyclability and reduce emissions. The increasing global concern about greenhouse gas emissions is likely to have a tremendous impact on the automotive business including the possible evolution to a hydrogen economy. Meanwhile, consumer demand for new amenities continues unabated and foreign competition is intensifying. The new vehicle designs that are required to meet rapidly changing industry needs, together with the increasing complexity of vehicles, are greatly increasing the challenge of high-volume manufacturing and the corresponding opportunities for NDE.

Fuel Efficiency

The challenges of significantly improving fuel efficiency and reducing emissions are driving the development of a host of new vehicle technologies, including hybrid and fuel-cell powertrains. The production of hybrid vehicles is focusing attention on energy-storage media, high-power electronics, electromechanical machinery, and fuel cells, which are a completely new technology that presents significant technical and manufacturing challenges. Modifications are also being made to internal-combustion engines, for example, to allow the use of alternative fuels and to enable lean-burn combustion. In general, the more complex and unfamiliar new vehicle technologies are, the more likely it is that NDE will be necessary to monitor manufacturing processes, inspect products, and monitor performance.

For any new vehicle technology, the need for inspection during the ramp up to production is a given. A potential barrier in transitioning to high-volume manufacturing is a lack of inspection techniques that meet the time, cost and logistical requirements for mass production. This issue is addressed in DOE's recently published roadmap focused on overcoming the technical and manufacturing challenges associated with commercial development of hydrogen fuel-cell vehicles.[2] The report calls for NDE techniques to replace current inspection methods that are described as off-line, manual measurements and destructive tests that slow the manufacturing process and add cost.

An example: fuel-cell vehicles

Fuel cells are based on an electrochemical process that converts hydrogen and oxygen to electricity that is used to drive one or more electric motors. Fuel-cell vehicles either use pure hydrogen as a fuel, or hydrogen derived from hydrocarbon fuels. Limited infrastructure currently exists for providing hydrogen, onboard reformers may be used to extract hydrogen from fuels such as methanol and natural gas. Onboard reformers greatly add to the complexity of what is already a complicated fuel system. In addition to the reformer, fuel-cell systems for vehicles have hundreds of cells. Ensuring the integrity of the seals for each cell is essential because a leak from a single one can degrade performance and potentially destroy the entire fuel-cell stack. The need for NDE during manufacturing is likely to be high to ensure that engineering specifications are met for complex systems and performance-critical parts. Ensuring optimal performance in service is also important, and for all hydrogen-powered vehicles, there is the need for on-board monitoring. For example, storage tanks may be monitored to detect leaks.

Recycling

Automobiles are a recycling success story. It is estimated that 75 to 80 percent of the vehicle's weight is recovered, including more than 90 percent of the metal. About half of the steel produced in the U.S. contains recycled scrap metal and end-of-life vehicles provide more than half of the source material for the scrap-metal industry. The recycling challenge for the future is to eliminate the disposal of automotive materials in landfills. Meeting this challenge means finding ways to recycle or replace non-

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[2] http://www.energy.gov/news/3098.htm

metallic materials including tires, plastics, textiles and glass, while also eliminating the use of toxic metals and other hazardous materials.

The obvious role of NDE is in providing techniques for the identification and sorting of materials. Although recycling is a destructive process, eliminating the need for nondestructive solutions, NDE techniques are used for material separation. For example, the magnetic techniques used to separate ferrous and non-ferrous metals were an important development in producing high-quality recycled steel. Radiography is used to identify carbide bits in titanium chips, and methods are under development for other separation applications, including use of laser-induced breakdown spectroscopy to identify different grades of aluminum-alloy scrap.

Beyond separation, recycling is a series of processes, and analogous to its role in manufacturing, NDE may have a role in process monitoring and in assuring the quality of the resulting products. Controlling processes to prevent degradation of material properties, and confirming the purity of the output stream are essential in ensuring the usability of recycled materials. In the end, the economic viability of recycling depends on maximizing recovery, reprocessing and reuse of automotive components and materials. Greater use of post-consumer recycled materials in the production of automobiles would go a long way towards creating a viable market, but as with any automotive material, their use requires proving quality and durability and demonstrating that engineering specifications can be met in high-volume manufacturing.

Business Challenges

Globalization of the automotive industry has had a dramatic impact on both the design process and the supply chain. Designs are developed around the world and around the clock. Manufacturers are less vertically integrated and increasingly rely on external engineering. Moreover, increased competition has significantly eroded resources available for engineering. In this environment, corporate and international standards are increasingly relied upon to ensure a common technical terminology, common materials, and common processes. More of these standards, including physical reference standards, are needed for the NDE of automotive materials.

While out-sourcing the production of components, there has also been a recent trend to require suppliers to perform the necessary measurements and inspections with limited auditing of the actual quality. It has always been difficult to adequately monitor the supplier base, and that challenge is increasingly difficult now with the rapidly expanding number of suppliers operating in a very cost-competitive market. OEMs may have to take more responsibility for NDE of supplier commodities to guarantee quality irrespective of where a part or material was manufactured.

Chapter 3. Hurdles to Greater Use of NDE

In general, it is not easy to introduce new technologies into the auto industry. Companies are large, risk adverse and cost conscious. NDE technologies that meet the technical requirements may still get mired in logistical or procedural quagmires, even if they are cost effective and provide better information than existing inspection methods. A crucial step in increasing the use of NDE is convincing the manufacturing community of its value, and this means overcoming both technical and non-technical hurdles.

The Realities of the Plant Environment

The implementation and long-term use of NDE technologies depends on their ability to work well in a high-volume production environment. To understand exactly what this means it is useful to consider the introduction of a new inspection system from the perspective of the plant manager. Along with being sensitive to cost, seeing things from this perspective also means paying close attention to logistical issues. For example, floor space is at a premium and it may be difficult to find a place to set up instrumentation. The space problem is further exacerbated if the NDE system is sensitive to noise, dust, or dirt or if there is an ergonomic issue associated with using the system on the plant floor.

The overriding requirement is that NDE cannot interfere with the production process. An inspection system that detects a discrepancy may trigger a chain of events that requires plant personnel to quickly identify the source of the problem and to take corrective action. If a containment action were initiated, all parts produced since the last inspection would be quarantined, individually inspected, and repaired or scrapped. Thus, it is imperative that any NDE system be extremely accurate.

The point has been made that the business case for NDE is enhanced by its potential to provide more and better information than is currently available. However, for this benefit to be realized, the reality of the production floor has to be understood and accounted for. Plant managers and engineers do not have the time to collect, organize and analyze tomes of data. NDE data has to be synthesized to provide readily interpretable information tailored for specific persons. A hurdle in distributing information is the lack of infrastructure in some plants for integrated process control and inspection. When infrastructure is unavailable to tie into, new NDE technologies are required to be stand-alone systems, increasing their cost and hampering interpretation of results, tracking, and timely dissemination of information. This, in turn, makes it much more difficult to demonstrate the value of the information provided by NDE systems.

NDE will not succeed in the automotive industry for manufacturing applications without plant support and acceptance. NDE cannot interfere with the smooth flow of production, and it should make the jobs of plant personnel easier, not more difficult. The realities of the factory floor have to be well understood and accounted for in designing NDE systems. In addition, the cost sensitivity of the auto industry cannot be over emphasized. The funds available for new equipment, training, maintenance and replacement parts are not unlimited.

Variability and Human Factors

There are several sources of variability in U.S. auto manufacturing that create a substantial challenge in providing accurate and repeatable results. A typical automobile is composed of twenty-to-thirty-thousand relatively inexpensive commodity pieces largely held together by three-to-four-thousand spot welds. Many production plants in the U.S. are aged and non-standardized, introducing variability in the manufacturing process at all steps, which in turn, introduces variability into the resulting products including stamped sheets, cast components, and assemblies. There is also greater variability in materials than in some other industries where NDE has found success, and this can affect material properties and dimensions.

Human factors can also make it difficult to obtain accurate and repeatable results. Many manufacturing and inspection processes are labor intensive, introducing variability attributed to differences in experience, training, fatigue, motivation, and fallibility. One way to address operator variability is through training. In traditional non-auto applications, NDE technicians are highly trained and specialize in particular techniques. Training is provided by professional NDE societies, and operators are required to undergo periodic skills certification, which ensures a skilled NDE workforce with up-to-date knowledge and experience. This approach has been used in the automotive industry but is problematic due to the high costs of training, job specialization, and skill retention. As an alternative to extensive operator training, intelligence can be built into NDE systems.

The Need for Standards

Developing standards for NDE systems and appropriate inspection protocols is essential. In most cases, NDE systems will be breaking new ground. Creating uniform standards across company lines and international boundaries would make it much easier and more cost effective for NDE suppliers to develop NDE systems for automotive applications. At the same time, there is a pressing need for methods that allow relatively fast validation of new NDE techniques on automotive parts and comparison of competing systems. The ability to quickly and reliably calibrate NDE systems in the field is also essential.

Cultural Barriers and the Inertia of the Status Quo

Historical and cultural issues also hamper adoption of NDE in the automotive sector. For example, the decades old method of validating spot weld quality using teardown persists. The challenge of overcoming the inertia of doing things the way they have always been done cannot be overlooked. The challenge can be significant, especially when it means spending money on validating technology, and writing new testing protocols and inspection standards. These hurdles, along with a lack of experience with NDE, often require proponents of NDE to overcome a perception of no-value added.

For all of the reasons discussed above, the greatest opportunities for NDE in the auto industry remain in the introduction of new materials and processes. New materials and processes require new testing protocols and standards. At the same time, new production lines offer the opportunity to build in inspection stations so that they are a part of the process rather than an awkward add-on to existing lines. The opportunities are greatest where NDE offers solutions to problems that threaten to slow down or block the introduction of new materials and processes. These cases stand to influence the culture by demonstrating the value of NDE, while at the same time providing the NDE community with valuable experience in what it takes to make systems work in an automotive environment.

Chapter 4. Gap Analysis

The NDE industry faces significant technical challenges that must be addressed to meet automotive needs. Rapidly evolving technology is advancing the development of devices and NDE systems that meet the cost, ease-of-use, portability and reliability required for automotive applications. For example, affordable computing power combined with high-speed data acquisition and transmission is enabling high-resolution imaging fast enough for process monitoring. Advances in sensor technology are reducing costs while improving resolution and expanding the range of what can be measured. Emerging wireless technologies have the advantage of relatively low installation costs and will allow deployment of large numbers of sensors that can be networked to enable distributed processing and communication between sensors and other devices. Advances in micro and nano engineering, along with development of Micro-Electro-Mechanical Systems (MEMS) are resulting in smaller and lighter components for sensors and portable systems. These advances are opening new doors for NDE in automotive applications, however, technical gaps need to be closed and the non-technical hurdles overcome.

The functional requirements and desirable attributes that will allow NDE systems to be used in automotive manufacturing are described below and summarized in Table 4.1. A gap analysis is provided in Table 4.2. The analysis identifies the gaps between where NDE technology is today and where it needs to be to meet automotive needs. The development path outlined in the table to bridge the gaps will be used to inform the prioritization and selection process for new NDE projects.

Requirements for NDE Systems

For existing applications in manufacturing, the NDE opportunity is to provide faster, better and/or less expensive techniques. Besides faster and less expensive, there are many ways to make existing monitoring and inspection techniques better. One example is developing systems that are more automated, and that has more built-in intelligence or provides more useful information in the form of better reports, trend indications, and alerts. Systems can be made more accurate and reliable and more robust for manufacturing applications. Anything that makes methods easier to use makes them better, for example, smaller and lighter systems are more portable, which increases their functionality and makes them more amenable to automation. Intuitive user interfaces makes systems easier to use. Agile NDE tools that can be used for a variety of applications are particularly attractive.

One strategy to improve cost effectiveness and to make it easier to implement new NDE technologies in the future is to develop platforms that integrate the best available technology, add value immediately, minimize barriers to incorporating emerging technologies at a later date, and that are as modular as possible so that they can be easily modified or adapted for new applications. A platform might be an inspection station that supports techniques used for inspection of multiple components or the infrastructure required for integrated process monitoring and control. Incubator projects that allow new technologies to be tested in realistic manufacturing environments would greatly improve chances for success. A systems approach also favors NDE, by ensuring that inspection requirements are considered in designs, material specifications, and manufacturing plans.

The obstacles described above point toward requirements in developing NDE technologies for automotive applications and implementation strategies, including:

- Systems must be easy to use; therefore, automated techniques are preferable as are built-in intelligence and calibration.
- Inspections need to be fast, corresponding to production cycle times.
- Inspections cannot interfere with manufacturing processes and equipment operation, and NDE needs to be robust enough to work reliably in harsh environments with minimal maintenance.
- Cost is important; so there must be a business case that justifies the cost of equipment, training, maintenance, and repairs.
- Inspection data must be synthesized to allow timely feedback to the process and delivered in a form that is readily useful to the customer.

Based on the discussion here and in the previous chapters, it is possible to identify the NDE attributes favorable for implementation in automotive applications. These attributes are listed in Table 4.1, followed by the gap analysis in Table 4.2. The basis of the plan put forth in the next chapter for developing the NDE technology that will enable greater use of lightweight materials is bridging the gap between the current state of NDE systems and the desired state that will make NDE cost effective and practical for high-volume, high-speed manufacturing.

Table 4.1 NDE Attributes Favorable for Implementation in Automotive Applications

Agile NDE tools useful from research and engineering to manufacturing and service
Fast measurement, analysis, and display
Accurate and reliable
Well tested and results demonstrated to be correlated to properties of interest
Built-in calibration procedure with standardized reference specimens
Standard hardware and software protocols; easy to access and output raw data
Built-in intelligence and diagnostic capability
Tracking and trend analysis; alerts to appropriate personnel
Customizable reports
Automated inspections
Noncontact
Able to handle complex geometries
Relatively insensitive to probe position or adjusts automatically
Less expensive than current options
Minimum training and maintenance requirements
Easy to use, ergonomically designed, portable, and lightweight
Robust in harsh manufacturing environments
Non-intrusive – does not interfere with the production process
Designed for compatibility with process control software/hardware

Table 4.2 Gap Analysis for Automotive NDE (page 1)

Current Status	Desired Status	Development Path
Speed		
Continuing improvements in sensors and computer processors means data acquisition speeds are generally acceptable, except possibly for large-scale and/or full-field applications. Data transfer to storage devices is sometimes problematic, as is conversion of data to readable formats. Data processing and display are often too slow.	Seamless and fast data handling including acquisition, storage, conversion and display. Information including full-field images, diagnostics and alerts in real time (see "Reporting" below).	OEMs must encourage suppliers to output data in standard formats. Faster data processing, analysis, and display algorithms. Built-in intelligence and expert systems. Decision and control software. Centralized processing Systems approach. Agile tools and platforms.
Reporting		
Reporting is often inadequate, requiring substantial effort by personnel to generate reports and analyze data. Summary reports and alerts, when available, cannot usually be customized, and come too late to be of use.	Customizable reports. Tracking and trend analysis. Diagnostics and alerts. Process feedback. Go/No-Go in real time with background tracking, analysis and reporting.	Built-in intelligence. Decision and control software. Flexible user interfaces. Design for compatibility with process control software. Plant-wide information systems to facilitate reporting and alerts.
Viability in a Production Environment		
Systems often fail to survive the heat, dust, dirt, and rough treatment in plants. Methods that require contact, couplant, line-of-sight access, or surface prep may be problematic. Safety is an issue for lasers and x-rays. Electromagnetic noise is an issue for wireless installations. Ergonomics not always favorable.	Robust to plant conditions and immune to rough treatment. Non-contact methods where possible. Single-sided access. No safety issues. Robust wireless technologies suitable for use in plants. Ergonomically designed systems that are easy to use in a plant environment.	Hardened instrumentation. More sensitive detectors to allow lower power devices. Lightweight, portable systems, with attention to ergonomics and ease of use.

Table 4.2 Gap Analysis for Automotive NDE (page 2)

Current Status	Desired Status	Development Path
Speed		
Continuing improvements in sensors and computer processors means data acquisition speeds are generally acceptable, except possibly for large-scale and/or full-field applications. Data transfer to storage devices is sometimes problematic, as is conversion of data to readable formats. Data processing and display are often too slow.	Seamless and fast data handling including acquisition, storage, conversion and display. Information including full-field images, diagnostics and alerts in real time (see "Reporting" below).	OEMs must encourage suppliers to output data in standard formats. Faster data processing, analysis, and display algorithms. Built-in intelligence and expert systems. Decision and control software. Centralized processing Systems approach. Agile tools and platforms.
Reporting		
Reporting is often inadequate, requiring substantial effort by personnel to generate reports and analyze data. Summary reports and alerts, when available, cannot usually be customized, and come too late to be of use.	Customizable reports. Tracking and trend analysis. Diagnostics and alerts. Process feedback. Go/No-Go in real time with background tracking, analysis and reporting.	Built-in intelligence. Decision and control software. Flexible user interfaces. Design for compatibility with process control software. Plant-wide information systems to facilitate reporting and alerts.
Viability in a Production Environment		
Systems often fail to survive the heat, dust, dirt, and rough treatment in plants. Methods that require contact, couplant, line-of-sight access, or surface prep may be problematic. Safety is an issue for lasers and x-rays. Electromagnetic noise is an issue for wireless installations. Ergonomics not always favorable.	Robust to plant conditions and immune to rough treatment. Non-contact methods where possible. Single-sided access. No safety issues. Robust wireless technologies suitable for use in plants. Ergonomically designed systems that are easy to use in a plant environment.	Hardened instrumentation. More sensitive detectors to allow lower power devices. Lightweight, portable systems, with attention to ergonomics and ease of use.

Table 4.2 Gap Analysis for Automotive NDE (page 3)

Current Status	Desired Status	Development Path
Speed		
Continuing improvements in sensors and computer processors means data acquisition speeds are generally acceptable, except possibly for large-scale and/or full-field applications. Data transfer to storage devices is sometimes problematic, as is conversion of data to readable formats. Data processing and display are often too slow.	Seamless and fast data handling including acquisition, storage, conversion and display. Information including full-field images, diagnostics and alerts in real time (see “Reporting” below).	OEMs must encourage suppliers to output data in standard formats. Faster data processing, analysis, and display algorithms. Built-in intelligence and expert systems. Decision and control software. Centralized processing Systems approach. Agile tools and platforms.
Reporting		
Reporting is often inadequate, requiring substantial effort by personnel to generate reports and analyze data. Summary reports and alerts, when available, cannot usually be customized, and come too late to be of use.	Customizable reports. Tracking and trend analysis. Diagnostics and alerts. Process feedback. Go/No-Go in real time with background tracking, analysis and reporting.	Built-in intelligence. Decision and control software. Flexible user interfaces. Design for compatibility with process control software. Plant-wide information systems to facilitate reporting and alerts.
Viability in a Production Environment		
Systems often fail to survive the heat, dust, dirt, and rough treatment in plants. Methods that require contact, couplant, line-of-sight access, or surface prep may be problematic. Safety is an issue for lasers and x-rays. Electromagnetic noise is an issue for wireless installations. Ergonomics not always favorable.	Robust to plant conditions and immune to rough treatment. Non-contact methods where possible. Single-sided access. No safety issues. Robust wireless technologies suitable for use in plants. Ergonomically designed systems that are easy to use in a plant environment.	Hardened instrumentation. More sensitive detectors to allow lower power devices. Lightweight, portable systems, with attention to ergonomics and ease of use.

Chapter 5. Guidelines for NDE Development for the Automotive Industry

NDE can play a significant role in accelerating the introduction and implementation of new products by ensuring their reliability and quality. The inspection challenge is formidable for advancing energy and environmental goals that might include internal combustion engines fueled by hydrogen in the medium-term and fuel-cell power plants in the long-term. The most pressing near-term need is for NDE techniques that will enable new products using lightweight materials. NDE is required to demonstrate the ability of new processes to reliably produce consistent, high-quality parts during high-volume manufacturing.

In concurrence with industry needs and government goals, potential NDE projects will be prioritized according to their ability to enable introduction of one or more materials or processes that contribute to lightweighting. Within this arena, there are several different categorizations that could be used for further prioritization. For example, NDE needs could be identified for each of the many materials under consideration, and then prioritized according to the likelihood that the material will make it into vehicles given that NDE requirements can be met. Alternatively, NDE needs could be specified for particular automotive assemblies, for example, engine blocks or body structures, and then prioritized according to the potential for material substitution that would contribute toward lightweighting. However, a significant drawback in focusing on materials or parts is that the future is difficult to predict. The automotive market, government priorities, and the world condition will all change, which, in turn, may change consumer demands, industry goals, government mandates and the corresponding challenges. At the same time, rapidly advancing technology will increase the material and technology options available to meet new and old challenges. If NDE research and development is tied to a particular material or component, it becomes necessary to forecast the future and pick winners and losers, making successful NDE technology transfer to the production floor much more risky.

For these reasons, prioritizing NDE projects based on materials or automotive components was rejected in favor of concentrating on the challenges associated with particular manufacturing processes and their products. No matter what materials are selected, they have to be built into cars. A tremendous advantage in focusing on processes is that contributions to manufacturing have the potential to contribute to more than one material and component, as well as the potential to improve the efficiency of current production using traditional automotive materials. Another advantage of focusing on processes is the potential to move NDE up-stream, toward on-line inspection and to integrate it with process control where the greatest benefits from NDE are realized.

High-Priority Applications

The areas identified where near-term needs are greatest for NDE are body materials, chassis and powertrain components, and assemblies. The high-priority needs identified in these functional areas are inspection techniques for sheets, castings, and joints, respectively. The choice of the body, chassis and powertrain is motivated in part by the need to focus on those areas that will contribute most to lightweighting; the body exterior accounts for roughly 35 to 40 percent of vehicle weight, while the chassis and powertrain account for another 45 percent.

There are manufacturing challenges associated with greater use of lightweight materials in each of these applications that have been discussed in the previous sections and that are summarized in more detail in Table 5.1. For body panels, manufacturing issues include formability and the tendency of some materials to spring back after stamping. The trend of using thinner gauges of sheet materials to reduce weight means that sheets are more susceptible to tearing during forming operations, requiring increased inspection. For casting, processes for lightweight materials are more difficult to control than for cast iron and tend to introduce discrepancies such as porosity and oxide inclusions. Castings are also becoming more complicated, requiring inspection methods that can handle complex shapes. New joining methods are being investigated for both existing applications and lightweight materials, and each comes with a new set of manufacturing challenges and corresponding NDE opportunities. For example, adhesive bonding is commonly used to join lightweight materials, and issues include the location and thickness of the adhesive, as well as the state of cure and the degree of adhesion.

Guidelines for Prioritizing Projects

At a minimum, projects are expected to contribute to achievement of USAMP, FreedomCAR and USCAR goals, while also meeting the high-priority NDE needs identified by industry. To ensure a more coordinated and forward-looking approach to selecting projects than has been used in the past, projects will also be prioritized based on their potential for closing the gaps between technology that is currently available, and what is needed to meet the requirements of high-volume automotive manufacturing. In summary, projects will be evaluated and prioritized according to their contributions toward:

- Enabling introduction of one or more materials that contributes to lightweighting and/or improving manufacturing efficiency.
- Providing an inspection solution to an identified problem associated with sheets, castings, or joints.
- Closing one or more of the technical gaps between commercially available NDE systems and what is required for high-volume automotive manufacturing.

To assure the greatest likelihood that the developed technology will be successfully implemented in plants, proposed projects will also be evaluated based on the answers to the following questions, which address the role of the technology and potential hurdles to implementation and adoption in high-volume manufacturing:

- Is the proposed work crucial for use of a material or process that is otherwise production ready?
- Will it be possible to test and evaluate the developed technology under realistic conditions?
- Does the proposed project have one or more industry champions capable of managing the project from R&D through implementation and adoption?

In addition to these primary considerations, projects will also be evaluated in the larger context of their contribution toward advancing the state of the art of automotive NDE. In this context, answers to the following questions will also provide guidance in selecting projects:

- Does the proposed project benefit more than one process, part, or product?
- Does the proposed work contribute to creating an infrastructure that will help enable NDE technologies in general?
- Is the proposed technique well suited to automation and high-speed on-line inspection?
- Will the project help to create a culture where NDE is valued; i.e., will the project’s value be obvious to a broad audience?

Although not always considered when evaluating technological options, creating a culture that values NDE and identifying industry champions are considered extremely important in meeting the overall objective of increasing the use of NDE in the automotive industry. There is increasing realization that successful technology transfer requires champions at each stage of development, from conceptualization and proof-of-concept, to prototype development and implementation. Developing a technology solution is not enough – implementation, testing, integration with existing systems, training, and customization all have to be fostered by industry champions to ensure adoption and acceptance of new technology. It is hoped that this document will support industry champions by helping to raise awareness of the potential benefits from increased use of NDE, and by identifying hurdles that have slowed down introduction of NDE in the past that must be overcome for greater success in the future. The short-term payoffs from successful implementation and adoption of NDE technologies are greater use of lightweight materials, and cost and energy savings derived from reduced waste and increased production efficiency. The long-term payoff is inspection integrated with process control that stands to greatly accelerate the introduction of new materials, processes and vehicle technologies.

Table 5.1 Near-Term Priorities for Automotive NDE

Industry Trends	Manufacturing Challenges	NDE Needs
Body Materials: Sheets		
Use of thinner gauges to reduce vehicle weight. Greater use of lightweight materials. Use of tailor-welded blanks with different gauge materials. Use of dissimilar metals. Use of composite sheets. Use of new coatings.	Reduced formability. Spring back during forming and stamping. Impact damage. Corrosion. Coatings.	Methods to detect tears. Better ways to verify joint quality in tailor-welded blanks. Methods to detect impact damage in composites. Techniques to measure residual stresses. Methods to verify the thickness and integrity of coatings.
Chassis and Powertrain Components: Castings		
Greater use of lightweight materials Higher power-density powertrains. Use of new casting processes. Increasingly complex castings.	New types of discrepancies. Tighter design tolerances. Quality of bearing surfaces. Hard, wear-resistant coatings.	Methods to identify, locate and characterize casting discrepancies. Methods to detect oxide inclusions. Methods to confirm proper heat treatment/case depth and coating quality. Techniques that can inspect complex shapes.
Assemblies: Joints		
Use of adhesive bonding for structural joints. Joining of dissimilar materials. Use of new welding and fastening methods. Joining sheets to castings.	Inspection requirements for structural adhesives. Inspection requirements for new welding and fastening processes. Costs of destructive testing. Corrosion. Thin-sheet attachments.	Methods to verify the integrity of adhesive bonds. Methods to verify the quality of new mechanical joining methods. Methods to identify discrepancies in welds. Methods to detect corrosion.