Proposal for Final Assembly Line at Ford's North Penn Electronic Facility: Driver Door and Driver Seat Module

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Project Abstract

Propose the process and layout for assembly of two automotive electronic modules at Ford's North Penn Electronics Facility in Lansdale, Pennsylvania. The final assembly process includes operations securing a printed wire board into a housing, full functional testing and programming, sorting and packing of the modules.

The two modules have different form factors, connector interfaces, and components. One of the modules has a unique requirement of being paired with incoming supplied parts and programmed to match those parts before being shipped as a kit.

The process and layout will be a modern assembly line minimizing labor and facilities costs, maximizing flexibility and line rate, and reusing as much equipment and tooling already in-house as possible.

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Executive Summary

This is a design proposal for a layout of an assembly line for the final assembly operations of two modules. The manufacturing line must be:

Highest quality
- Robust system design, with high uptime and yields, ease of maintenance
- Assemble the components resulting in the highest quality product

Minimal cost
- Facilities and tooling as inexpensive as possible
- Reuse as much in-house equipment as possible
- Require as little labor as possible

Maximum flexibility
- Manufacture at least 250 modules per hour
- Zero changeover time between the two modules
- Efficient over fluctuating volumes and model mixes
- Able to add additional models easily

This assembly process is more than a trivial problem due to the two modules having different form factors, connector interfaces, and components, as well as one of the modules has a unique requirement of being paired with incoming supplied parts and programmed to match those parts before being shipped as a kit.

This proposal will identify and address all relevant factors in determining the optimal line layout for the final assembly of these two products. The final assembly process includes operations securing a printed wire board into a housing, sorting and packing of the modules, and full functional testing and programming.

Background Overview

Ford Motor Company's electronics manufacturing plant in Lansdale, Pennsylvania, North Penn Electronics Facility (NPEF), has been sourced for the Driver Door Module (DDM) and Driver Seat Module (DSM) for the 1999 luxury vehicle (previously named Mark VIII), 1999 Jaguar XJ200, and 1999 Windstar. These modules are part of the Functionally Integrated Electronic Module (FIEM) family which perform various functions in the car while talking to each other on the Ford Standard Corporate Protocol (SCP) network. This network will save money in the miles of wiring it replaces, and allows a simple way for all electronic modules to communicate with all the other modules to which it should receive or send information.

The DDM module is responsible for operating driver door locks, driver window, and Remote Keyless Entry (RKE) into the vehicle. The DSM controls the electric adjustment of the driver's seat. In operation, when these modules are on the SCP network, they can talk with other electronic modules on the network for increased features and thus value to the customer. For example, when a customer activates the RKE door unlock function while walking toward the vehicle, the DDM module will decode the unlocking signal, unlock the doors and can send a message to the DSM to adjust the seat to the exact preset position for that specific customer. See figure 1 for a description of functional features of all four FIEM modules.

PRODUCT VOLUME AND MIX REQUIREMENTS

More than 650,000 modules must be manufactured on the DDM-DSM final assembly line annually. The Windstar DDM is the highest volume product on the line, as detailed below in figure 2.

Program Name	Vehicle Name	Module	Peak Annual Volume	
X200	'99 XJ200 Jaguar	DDM	124,000	
		DSM	74,000	
DEW98	'99 Mark VIII replacement	DDM	61,000	
		DSM	61,000	
WIN126	'99 Windstar	DDM	354,000	
		Total	674,000	(divided into 250 days results in 2696 modules per day)

Figure 2. Peak volumes for DDM and DSM modules.

To manufacture 674,000 modules per year, assuming 250 working days in a year requires 2,696 modules per day to be manufactured. Assuming 7.2 hours of production for shift two (day shift) and shift three (afternoons) after eliminating time for standard lunch and breaks as required by the union, and assuming 6 hours for shift one (midnights), the decision must be made on how many shifts to operate.

Number Shifts	Hours per Day	Modules/Hour Net	Modules/Hour Gross	Cycle Time Per Unit
1	7.2	374	468	7.7 seconds
2	14.4	187	234	15.4 seconds
3	20.4	132	165	21.8 seconds

Figure 3. Options relating volume requirements to hourly rates and cycle times per unit. Note that modules per hour gross takes into consideration downtime to meet required volumes.

The goal is to minimize the number of shifts in order to save labor cost (manning for a whole shift will carry a significant amount of cost with direct labor as well as overhead support costs), and the goal to chose a cycle time realistically attainable with final assembly automation. Figure 3 compares the number of shifts and the related modules per hour that must be produced to obtain the required customer volumes. Note that it is important to factor in process inefficiencies, which are assumed to result in production at 80% of capacity (typical of current assembly processes in existence at NPEF today), to reach a realistic "Modules per Hour Gross" number in figure 3. This downtime is typically due to “starving” the line with lack of materials at a station to run, machine faults, or blocking the outgoing processed material due to backups in a proceeding process. The option with two shifts is the most reasonable scenario.

Implementing a Flexible Assembly Method

COMPETITIVE ENVIRONMENT

> Once more the country is passing through a grave crisis. The people and their leaders believe that they must be prepared to defend it against any threat to their political and economic institutions... Industry is straining every resource at its command...[1]

The above quote pictures the fierce competition in the twentieth century. It is actually a quote from the World War II time period about manufacturing and management methods. Then, just as now, automation was viewed as a resource for more efficient production, although some more recent, different impending threats exist and require different tactics in response.

The industrial revolution has brought us from manual craftsman manufacturing and assembly method to hard-tooled automatic processes and the assembly operation methods of Henry Ford. These hard-tooled automation methods are more suited for manufacturing many of the same product (see figure 4).

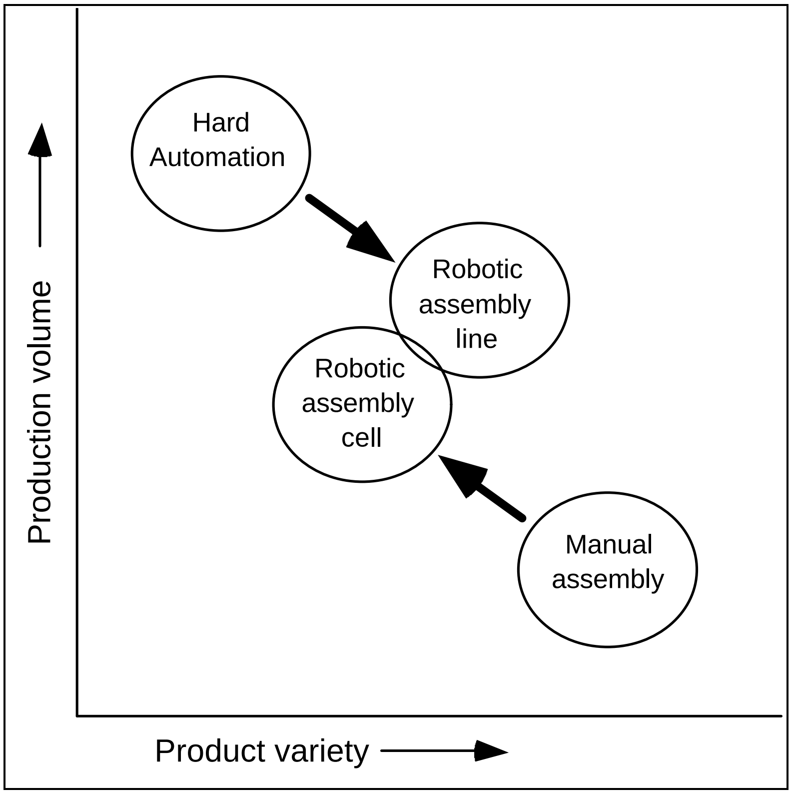


Figure 4. Comparison of different assembly systems. [2]

REASONS FOR AUTOMATION

Automation has been implemented in manufacturing environments for a variety of good reasons, including[3]:

- Increased productivity
- High cost of labor in a manual operation
- Improved product quality; automation has the effect of removing all possibility of human error.
- Reduced manufacturing lead time
- Reduction of in-process inventory
- High cost of not automating; intangible ways such as better labor relations, better company image.
- Operations too intricate to be handled manually
- Hazardous environments; noisy, hot, or chemical environments require machines.[4]
- Required product volumes; volumes the or speed of production may be such that manual assembly may be impractical. The number of operators required to achieve the production targets may pose financial, space, or recruitment problems.[5]

INTELLIGENT IMPLEMENTATION OF AUTOMATION AND MANUAL PROCESSES

Just implementing an automated assembly process is no guarantee of the most efficient manufacturing process, as history has shown. Almost as fast as an interest in robotics surged into a frenzy in the 1980's, it ebbed away, leaving many people disillusioned with their newly acquired robots.[6] Process engineers need to consider the tasks in a manufacturing process and examine which are best suited to machines and which are best suited to people. We have entered the era of lean and agile manufacturing. William Bourn, assembly system engineer at Modular Automation states it well:

> People are the best type of automation you can get. The trouble is, they make mistakes, need motivating, must be paid, insist on holidays, and are easily bored. That's when machines come in... it is all a matter of cost... In most cases, it would be possible to provide completely automated systems for almost any operation. But when you work out the figures, people usually have to be involved somewhere. For example: if we automate an operation totally, the system could be less cost-effective

than a semi-automatic system. Perhaps, one of the operators is doing a very complex job or moving large or awkward pieces. In that case the cost of automating that function would be out of proportion and the risks to the efficiency of the system, unacceptable. Our job is to achieve the right balance between automation and manual assembly to make sure we get the best from both.[7]

PEOPLE	MACHINES
Require Training	Require more time than people to initially setup
Need to be managed	Good in hazardous, noisy, or clean environments
Tooling costs need to be considered	
Good at handling odd shapes or large workpieces, often good for the beginning and end of lines	Good at tasks requiring high cycle times and requiring high accuracy and repeatability (e.g. loading reject and good units in the correct appropriate location every time).
Operations where components vary in shape (e.g. wiring harnesses)	Good when components are very similar and to specific tolerances
Varying work pace (people learn)	Every cycle takes the same time
Loading must be right; not too little to prevent boredom that creates errors and not too much to starve proceeding processes	Runs with consistent cycle time, but can be down extended periods when faulted (wires broken, etc.)
Infinitely flexible Often unreliable	Not as flexible as people. Good at performing same task, repeatedly, without stopping

Figure 5. Contrasting machines and people.

It is apparent from figure 5 and paragraphs above that people and machines both have benefits and vices that need to be considered when developing a manufacturing process while balancing cost and quality requirements. Not only must the right balance be chosen, but just as important is the human-machine interface.

Not only must the question of automation or manual operations be considered, but whether the manufacturing system is flexible enough to change quickly in today's economic environment. As was said earlier, we have left both the past manual craftsman methods and the hard tooled automation of the industrial revolution, and entered an era requiring lean, agile manufacturing processes.

FLEXIBLE MANUFACTURING SYSTEM

Competition facing manufacturers has intensified in recent years as a consequence of deregulation and the entry into local markets of highly efficient, innovative international manufacturers. The nature of competition has also been modified with firms competing in "bundles" of product enhancements including quality, rapid and flexible response to customer needs, reliable delivery, service and warranty as well as conventional product characteristics such as physical attributes and cost. There is considerable evidence supporting the links between manufacturing flexibility and enhanced performance. A study by Meyer et. al, investigated 576 firms from USA, Japan, and Europe, and found that the world's most effective firms were achieving high levels of manufacturing flexibility[8]. They concluded that the ability to attain manufacturing flexibility in a cost-effective way will be the main competitive challenge in the 1990s.

The general objective of the manufacturing process is to produce highest quality product for the lowest possible cost. The cost per unit is affected by a number of items, including the costs of facility construction and operation, capital equipment, work carried in process, labor, capital equipment use, and yields.[9] Flexibility is defined as the ability of a system or facility to adjust to changes in its internal or external environment.[10] Flexible automation can positively affect each of these cost factors. Below, we will discuss different aspects of a flexible manufacturing process.

Defining Flexibility

ASPECTS OF FLEXIBILITY

While global competition has clearly underlined the need for enhanced productivity, shorter product life cycles and greater product proliferation and market fragmentation indicate that manufacturing flexibility is essential for the long-term viability of many firms.[11]

Flexibility of manufacturing systems has been conventionally associated with their ability to manufacture a variety of part types, however, there are many facets to flexibility. Some definitions of types are given below.

Volume flexibility is a measure of a system's capability to be operated profitably at different volumes of the existing part types. High volume flexibility in essence implies a low break-even point.[12] This is the ability to vary production with no detrimental effect on efficiency and quality, and it takes into account demand fluctuation and fraction of product that needs repair and reintroduction.[13]

Machine Flexibility relates to the ease with which a machine can perform various operations without requiring a prohibitive effort in switching from one operation to another.[14] It is determined, in part, by the number of different operations that can be carried out at the machine and the time taken to switch among these operations.[15]

Routing or material handling flexibility is a measure of the ease and alternative routes with which different part types can be transported and properly positioned and processed at the various machine tools in a system. This could be expressed, for example by the degree to which the various machines in the system are directly connected, as well as the average travel time between machines.[16]

Expansion flexibility refers to a system's ability of being built and expanded incrementally. It increases with a reduction in the marginal capital investment required for providing additional capacity.[17]

Product mix or process flexibility is a measure of the volume of all the possible part types that a system can produce without incurring any major setup time[18] or significant degradation in performance.[19]

New product flexibility refers to the ability to rapidly introduce a new product in the process.[20] Each time a new product is introduced, the facility experiences a cost to set up the facility (e.g. tooling cost, reprogramming cost, retraining cost, etc.), plus a cost associated with the downtime needed for setup, which should be minimal for a more flexible plant.

Market flexibility is the ability of a system to efficiently adapt to changing market conditions. Short term market flexibility measures the time and effort to deal with changes in customer orders, while the long term market flexibility addresses a system's ability to cope with changes in customer needs, short product life cycles, and changes in product technology.[21]

Flexibility is required to maintain continuity in operations in the face of unforeseen events, such as machine breakdowns, minor design changes, unreliable raw material supplies, unexpected demand surges, etc. While the overall flexibility of a system is constrained by decisions made at the system design stage, the realized short-term flexibility depends significantly upon pre-production decisions, such as module design or products chosen to run through the same process. It should also be noted that the physical system can be designed to optimize certain types of flexibility over other types of flexibility according to organizational goals.[22]

TRENDS IN FLEXIBLE AUTOMATION IMPLEMENTATION

David Upton, assistant professor at the Harvard Business School notes that more complex automation does not necessarily result in an increase in flexibility:

> One surprising observation has been that the higher level of computerization, the less flexible the plant's ability to make a large range of products or to change swiftly between products.... One of the culprits is software. Once a process is highly computerized it can be very difficult to change it in a way that the designers didn't anticipate... Highly computerized production systems... can be more difficult to adapt to unanticipated changes than relatively unsophisticated production equipment ever was. The software engineers in the factories also tend to remove less frequently used capabilities from their systems so that they can run on auto pilot [or fail to support specific features that take considerable time to modify]...
>
> Another problem is that manufacturers too often turn to computerization as a quick fix rather than taking the time to figure out what they really need to do to make their factories flexible. All research to date shows that attempts to "buy" flexibility through technological fixes are nowhere near as successful as sustained improvement over time. Plants that managers think are flexible tend to get a lot of practice and get better at it. It's a self-fulfilling belief. We've found that flexibility is determined much more by people in the plants, their industry experience, and the practice they get than by the use of a certain type of technology.[23]

Newer, more automated processes tend many times to be associated with less mix and new product flexibility.[24] Studies have also shown that US. companies have used flexible manufacturing systems for high volume production of a few parts rather than for high-variety production of many parts at low cost per unit. For example, Japanese systems produced on the average more than nine times as many part types, and averaged more than 20 times as many new part types introduced per year. Thus, Japanese companies have exploited "mix flexibility" and "new product flexibility" much better than the US. has.[25]

Positive relationships with suppliers and subcontractors have been shown to positively affect both product mix, new product, and volume flexibility. It has also been found in studies that there is no relationship between quality and flexibility or cost and flexibility.[26]

Designing a flexible manufacturing system involves balancing cost effectiveness with short and long term gains, optimizing processes with the implementation of both manual and automated processes. Spending more money, or implementing a more complex system in no way guarantees flexibility. A thoughtful investigation in the manufacturing system design will result in the most flexible system. This "cost-effective flexibility" ideal will be the manner in which the NPEF DDM-DSM Final Assembly process is designed.

Module Complexity and Process Requirements

The following complexity issues related to the DDM and DSM modules must be addressed in the proposed flexible assembly system.

FAMILIES

There are essentially two families that will be run on the DDM-DSM final assembly line, the DDM family and the DSM family. One important factor to consider when planning a flexible process is determining the products, or part types, that will run on the assembly line[27]. The DDM and DSM have many similar processing requirements that make them compatible on the same assembly line:

- similar polypropylene housings that snap shut to hold the circuit board in place
- functional testing processes will be similar on driving outputs, with testers using similar loads
- similar end item labeling requirements, sort and packing requirements

DSM AND DDM DIFFERENCES

The DSM currently only has one model type in its family, requiring only one board with the same components every time it is built. The DDM has two physical circuit boards that can be populated differently for a total of approximately four distinct DDM models. Please see figures 6 and 7 to see the difference in board size and components between the DDM and DSM, and figures 8 and 9 for the different housing designs (that the boards will be placed into in the final assembly process). Note the different connector styles that will require multiple tester nests to attach to the module and stimulate and measure the connector pins in a manner similar to the actual functional performance of the module.

DIRECT CUSTOMERS

The DSM and the DDM are shipped to different customers by the in-plant warehouse. The DSM module is sent to the seat manufacturer for the respective vehicle programs, Johnson Controls, Inc. (JCI). JCI will then send the completed seat to the respective Body and Assembly (B&A) plants that put together the automobiles. The DDM module will be shipped to a Keykert, who integrates all the components in the door into a door "cassette", including the window guides, speakers, DDM module, window up and down mechanisms. Having the assemblies completed separately allows the B&A plant to speed operations and focus on assembling the vehicle together properly. The system must be able to pack the modules in different boxes and identify them as going to different customers.

DDM FEATURE SETS

The Mark VIII luxury vehicle replacement and XJ200 Jaguar vehicles will have very similar DDM modules. However, the Windstar will have a module with much fewer features to minimize the vehicle cost to the customer. Only RKE and SCP communication functions will be on the Windstar module - not any of the door lock and window features, for example.

The full featured module has an additional connector able to handle the high power outputs to the driver door lock and window, whereas the module without the additional features does not require the additional 4-way connector. This requires the implementation of two housings, one with the hole for the additional connector and one without. This will be handled at the housing supplier with an insert in the mold that can be removed or added depending on what housing is in demand. This is less expensive than placing an additional connector that will not be used in the Windstar DDM. Note that approximately two-thirds of all DDM modules will be for Windstar. The assembly line must be able to detect and insure that the proper housing is used with the correct circuit board.

DDM OPERATING FREQUENCY

The dimensions of model complexity for the DDM are related to frequency of operation and keyfob type matched to the DDM as per the customer. The DDM, since it has the RKE function, must be designed to work with different radio frequencies (RF) according to the country government regulations on RF applications. In North America, the FCC has reserved the frequency 315 MHz. The DDM modules must be designed and manufactured with four different frequencies:

- North American (315 Hz)
- Europe (433.92 Hz)
- Australia (303.825 Hz)
- Japan (240.4 Hz)

KEYFOB OPERATING FREQUENCY AND STYLE

Although there has been an effort to reduce keyfob complexity, there are still many keyfobs that differ according to look and feel, number of buttons, and frequency of operation. The keyfob circuit board, like the DDM, is different according to frequency of operation. Vehicle programs also require different number of buttons. For example, in Japan, a "Panic" feature is not legal on cars (drivers can press the panic button on the fob to start their horn pulsing and lights blinking to attract attention in an emergency situation), limiting some keyfobs to the minimal number of two buttons (lock and unlock doors). Some keyfobs have a button for opening the trunk. However, another extreme in the case of the Windstar minivan, is five buttons - lock, unlock, panic, and automatic open/close of both side doors. Please see figure 10 to understand the keyfob complexity.

DDM-KEYFOB MATCHING (MATING)

So, for the DDM-keyfob system to function, the keyfobs and the DDM must match frequency, as well as the correct style of keyfob for the vehicle application. Note that typically two keyfobs must be mated to the DDM and shipped to the customer as a kit. However, there are some cases where the DDM will not be mated to keyfobs and the DDM module will be shipped out alone, and the keyfobs will be mated and programmed to the DDM in the vehicle B&A plant. This will be done in the case of the Jaguar XJ200 to save on shipping expenses. The keyfobs will be made in Europe, so sending the fobs to North America and then back to Europe as a kit is not financially sound. There are over 11 possible DDM-keyfob kits. The assembly line must be able to insure the integrity of the DDM-keyfob match throughout the assembly process.

Each keyfob has a unique Transmission Identification Code (TIC) that must be programmed into the DDM. This allows only the specific unique keyfobs to work with that specific DDM. Every time a keyfob button is pressed, all automobiles that have the RKE feature within range of the signal, will have the DDM receive the signal, unscramble the encoded transmission, and then determine if the TIC matches any of the TICs that have been programmed into the DDM. If the TIC is programmed into the DDM then the DDM will process and perform the command (unlock, lock, panic, etc.).

One important concern with DDM-keyfob matching must be noted. After the DDM is programmed, the keyfobs kitted with the module must not be separated from the module until the B&A plant. The DDM door cassette supplier (described in above section, Direct Customers) must keep the keyfobs attached to the DDM until the cassette reaches the B&A plant. Current vehicle audits in B&A plants frequently identify keyfob inoperability as an issue. This is due to keyfobs being separated in the B&A plant due to operator or process error. The DDM-keyfob kitting process must help minimize this if possible.

INCOMING KEYFOB INCOMING QUALITY CONCERNS
There are also significant quality concerns with keyfob suppliers that must be accounted for in the manufacturing system. Two suppliers will be supplying keyfobs to North Penn. One supplier has been manufacturing RKE keyfobs for over five years, but recently lost and regained Ford Q1 rating due to the number of warranty and plant returns. The other supplier currently only supplies a small number of keyfobs to the Japanese market and will be building a new facility in Mexico for high volume production.

PASSIVE ENTRY
Some DDM-keyfob systems have two way communication with the keyfobs instead of one way (from the keyfob to the DDM). This feature has been named "Passive Entry". This additional capability allows the DDM to tell the other modules in the vehicle that the driver is nearby the vehicle, allowing the vehicle to set the seat, radio stations, etc., to those preset by the driver at an earlier time. If the keyfob was constantly sending out a signal to eventually be received by the proper DDM, the keyfob’s lithium battery would die in matter of weeks. So, instead, the DDM (with passive entry function) with the greater power supply (car battery), sends out a signal at a specific interval to all keyfobs in the area. Passive Entry keyfobs that have had their TICS programmed in the DDM will respond back to the DDM, telling the DDM that they are near. Only certain DDMs and keyfobs have this Passive Entry feature, and is one more variation that the manufacturing process must account for.

BRACKETS
Windstar DDM modules may require a bracket to allow them to be mounted properly in the vehicle. Note that this module constitutes approximately half the volume of all the modules assembled in this process.

Process Steps

The DDM/DSM Final Assembly line must do the following:

- Place the DDM or DSM populated (electrical components and connectors have been placed and soldered down) printed wire board (PWB) board into a polypropylene housing.
- Once the PWB is in the housing, the housing must be closed, and label information on the PWB must be transferred to an end item label on the housing. Both the PWB and end item label will include information about the specific DDM model type and unique serial number for module traceability.
- Kit DDM modules with two (or sometimes zero) keyfobs.
- Functionally test both DDM and DSM modules. Test failures must be routed to a reject lane or lanes to be troubleshot and repaired.
- Test the DDM for RF receiving sensitivity.
- Program the DDM module to respond to the specific keyfobs, and then packaged as a kit, insuring that the keyfobs are not separated from the DDM.

- Match the DDM module with the correct set of keyfobs as required by the end-item customer.
- Pack both DDM and DSM modules in a box correctly (all the same type) and ship to the customer.
- Attach a bracket to certain models of DDM modules.

Before Defining the Manufacturing Process

There are certain actions that should be taken before defining the manufacturing process for a product.

DESIGN FOR MANUFACTURE

Many papers and books relate the ineffective practice of design engineers throwing a product design over the wall to the manufacturing organization. Until this wall between designers and manufacturing comes down, engineers will never be able to take full advantage of their company's capabilities and develop the most cost-effective designs. On this program, manufacturing and design engineers have worked together at Ford to make the highest quality and lowest cost product. So far, the DDM and DSM designs have been modified in the following manner:

- Both the DSM and DDM have implemented a snap-shut polypropylene housing which is easy to close, and requires similar processes and controls to assemble
- Designers and manufacturing engineers have met with "Shared-X sessions", where the assembly is shown on a workstation at both the design and manufacturing site where discussions and changes in the design can take place real-time to resolve concerns. Weekly formal and innumerable informal discussions have taken place between designers and manufacturing engineers.
- The DDM antenna was redesigned to insure ease of assembly to the circuit board in the component insertion portion of the manufacturing line. It is also more stable to insure that the antenna is located properly on the board to insure proper fit when the board (with the antenna soldered down) is placed into the housing.
- Effort is being made to require the DDM keyfob suppliers to put two keyfobs in one bag, preventing mixing of the keyfobs in the process or at the customer site.
- The packaging has been simplified on the end-item DDM. Instead of requiring two keyfobs to be placed into another bag to hold both keyfobs, then taping the keyfobs to the DDM, and then placing a sticker with the kit information on the kit, the complete kit has been simplified. Keyfobs in their individual bags will be taped to the DDM with a label that will act like tape (securing the keyfobs to the board) as well as having the kit information on the label, essentially eliminating two steps in the kitting operation.
- To facilitate high rates of assembly, DDMs have been designed to be programmed via an SCP link during functional test to program the keyfob TIC information, instead of requiring an actual RF signal from a keyfob to program the TIC in the DDM. This also eliminates the need for an RF enclosure at final functional test, which would complicate the process.

CUSTOMER INVOLVEMENT

Involvement with the customer up front will insure that all expectations will be met, and hopefully exceeded. Regular monthly reviews with the customer, as well as forwarding information on a regular basis as to the design and proposed manufacturing process insure that manufacturing process will address all potential customer concerns.

CROSS-FUNCTIONAL MANUFACTURING TEAMS

Knowledgeable people must be involved at the right times in a project. Regular peer reviews with other product areas in the plant to discuss assembly line concepts, involving skilled trades in all processes, directing regular project reviews with suppliers, and having a centralized approach to integration (integration guidelines and standards set) all insure the best manufacturing process possible.

Process Improvement Information

The design of a flexible manufacturing process must consider the information required at each level of the system and how to get such information to the people who need it, in order to improve those processes continually over time. Achieving process consistency and increasing its robustness requires understanding and controlling the major causes of variation in the process, of which there are two basic forms:[28]

- Normal variation. Small differences in materials, people, equipment, environmental conditions, and procedures may produce small differences even when the process is operating as designed under expected environmental conditions.
- Abnormal variations arise through unusual events that produce process characteristics falling outside the acceptable range. They may be due to gross errors in procedure, or to major changes in materials or environment.

Reactive control alone with this variation in the process will not be able to improve the consistency or precision of a process. Preventing operations from exceeding limits requires that one eliminate the sources of abnormal variation. Preventive control requires deeper knowledge about cause-and-effect relationships: it requires that one understand (at least in a rough way) how different variables and their interaction affect performance and are, in turn, affected by environmental conditions.[29] Understanding and eliminating this variation is comparable to reducing the water level of a lake to expose the rocks hidden underneath. The largest rocks stick out of the water first, and must be dealt with, to sail across the lake safely. As the level of water level decreases, different rocks come to the surface.[30]

Both reactive and preventive control focus on current operations and are achieved primarily through the actions of those members of the manufacturing organization who are most directly involved with daily production: operators, technicians, supervisors, and technical specialists. A manufacturing organization cannot increase the precision of a process without first developing the knowledge and capabilities that underlie preventive control. In a factory that relies primarily on reactive control, even a small change in material flows and plant layout can be traumatic. On the other hand, one that has mastered progressive control can make such changes gracefully, without breaking stride.[31]

A flexible manufacturing system can be viewed as consisting of three primary subsystems:
- workstations
- storage and transportation
- information flow and control

Of the three subsystems, information flow and control is the least understood and the least studied.[32] It has been repeatedly documented in literature that information systems are the primary source of problems in flexible manufacturing system implementation. Possible problems when implementing a flexible manufacturing system:
- unsatisfactory design
- inadequate cooperation between designers, users, and vendors
- problems associated with a lack of system understanding
- lack of training
- interface issues related to integration

Development strategies must include the integration of machines, operators and software. Critical success factors, "those things that must go well to ensure the overall success of the project" follow:[33]
- Simplification of the production process prior to the design of the manufacturing information system.
- Explicit determination of system interface, database and data format requirements, and communication network requirements early in the design process.
- A simple, unambiguous method to communicate the requirements and view of the flexible manufacturing system information system design.
- Systems specialists and vendors made subservient to the users and user representatives although the team approach is intended to promote cooperation among team members. The users need to be ultimately involved in performing acceptance testing of the software as well as documentation.
- Funding of information system projects by project manager on a contractual basis (the requirements of a project contract were not considered fulfilled until the users "signed-off").
- Bottom-up, phased-in integration of the information system with the production system.

In 1996, large information-systems projects have not had the greatest track record:[34]
- 27% were completed on time and budget, with features and functions as initially specified.
- 33% were completed but late, over budget and with fewer features than specified.
- 40% were canceled at some point during the development cycle.

In order to avoid the large pitfalls that await delay and cripple a manufacturing system, care must be taken in interfacing and designing a flexible manufacturing system and how it manages required information.

NORTH PENN COMPUTER INTEGRATED MANUFACTURING (CIM) APPLICATIONS
NPEF has developed applications with Ford corporate staff to work with automation. Many applications obtain information from machines and place this information into a database to allow easy access from a number of interfaces (including e-mail, automatic paging, batch reports, real-time reports) that can be tailored to the users' preference. Information such as the routing history of a module, is also available to validate, real-time, in the manufacturing process whether a module has gone through the proper process steps with the proper results or recall information related to the unit upstream to complete the processing of the module. For example, this would be used to determine if a module that failed test was accidentally placed back in the assembly process in error by an operator.

These applications are implemented via flexible configuration files with standard message and data formats, and standard protocols. The debugging of this system over time has allowed it to become more robust. However, intelligent application of these NPEF systems, such as minimizing validation points, will be proposed in the DDM-DSM manufacturing process, since each validation point must also be viewed as a single point of failure of the assembly process. These data gathering and validation applications will be evaluated and go through an acceptance testing just as every other piece of equipment on the assembly line, and efforts will be made to minimize dependence upon these higher, more complex levels of control to keep the line from producing product in the event of information system failures when the assembly equipment, adding most value to the product, is running well.

Flexible Module Transportation Concept

REUSING EXISTING FLEXIBLE TRANSPORTATION SYSTEM
Since the DDM and DSM modules are completely different physical shapes (form factors), and the DDM requires a kitting with keyfobs, pallets are the ideal way to transport these modules to each process. Another product in the NPEF, the Electronic Distributorless Ignition System, is decreasing in volumes and going to a semi-automatic operation before the end of 1996. The assembly system will have a large number of Bosch conveyors and pallets that can be reused for the DDM-DSM final assembly process (since the pallets are the proper size to easily hold a DDM-keyfob kit or a DSM), saving large amounts of investment capital. The Bosch conveyor-pallet system is relatively modular and can be relatively easily reconfigured, required, and reprogrammed for the DDM-DSM application. They have proven their durability on the older assembly line and maintenance repairs are relatively easy (e.g. replacing a continuous belt by splicing, swapping motor mechanisms with a few bolts).

LOOP LAYOUT
Since the pallets will be emptied upon packing the completed modules into a box for a customer, it makes sense to have the line in the shape of a loop, to allow the empty pallets to automatically return to the beginning of the line where they will be needed again for processing of another module. This layout also allows transfer of products on and off the primary handling system to allow unobstructed flow of work to flow into and out of parallel processes (like the testing operation). One load station and one unload station will be located at opposite ends of the loop.[35] Please see figure 11 for the proposed process layout.

PALLET DESIGN CONSIDERATIONS
Fixtures, or pallets, interface the product to the process. When properly designed they can make the interface optimal. However, typical fixturing and pallet problems can arise[36]:
- Fixtures often need to be changed or modified as additional products are added to a production system, resulting in costly and time consuming modifications.
- Fixtures need to be very precise in order to achieve the tolerances required of the finished part.

- Part tolerances often need to be made tighter than necessary in order to achieve the tolerances required of the finished part.
- Time consuming setup routines and pre-machining are often needed to eliminate and reduce distortion of the part in the process.
- New fixtures need to be designed each time a design change is made or new product variant is introduced.
- For a large variety of product variants, a large inventory of different fixtures must be maintained resulting in excessive overhead costs associated with storage, retrieval, changeover, and maintenance of fixtures.

These problems can be avoided by implementing agile fixturing techniques such as modular fixture kits. Modular fixturing kits are commercially available, and are based on common elements fixtured to a plate with grids of holes or slots to attach the components (see figure 12). Modular fixturing systems are commercially available from a variety of vendors, and the use of such kits saves the cost of machining a large number of unique pallets for each product, pallet inventory costs, fixture assembly time, reduced fixture design time (typically from 3 days to 3 hours), and fixture construction time (typically from 4 weeks to 4 hours).[37]

Of course, one concern with flexible fixtures is that they may not stay fixed over time. Fixture pieces that move over time will cause parts to be incorrectly processed (e.g. failing functional test because the testing harness cannot be automatically connected to the module due to shifted module locating pins). This negative possibility must be considered and weighed against the other benefits of a flexible pallet design.

The goal for the DDM/DSM line should be one pallet design that can accommodate both a DSM module and a DDM module (with keyfobs), to minimize changeover time. One pallet design for both module "form factors" (different physical forms) will result in no lost time or effort in changing over pallets when deciding to process the other type module.

The height of both modules in the pallet may need to be the same to allow the same end-item label machine to place a label on either type module, DDM or DSM. The labeling equipment must be investigated to determine if this is a requirement for the pallets or not.

PRODUCT FLOW
The layout of the assembly process will be in a product flow type arrangement to produce the product as efficiently as possible in large volumes. The work in progress is moved by a conveyor or similar means from one station to the next. The product is progressively fabricated as it flows through the sequence of operations.[38]

FLEXIBLE CHANGEOVER IN WORKSTATIONS AND ROUTING - RFID TAGS
On each pallet will be at least one module (either a DDM or DSM) and possibly two keyfobs (with most DDMs). These three components will all have barcodes associated with them. The DDM and DSM have a barcode (including model type of board related to features and frequency and unique serial number) on the printed wire board (PWB, which will be transferred to the housing) and the DDM keyfobs each have their own barcodes (including frequency and style of keyfobs and unique TIC).
Throughout the final assembly process this information is needed.

The module and keyfob information can be stored in an RFID (Radio Frequency Identification) tag on each pallet. This will allow only one RF tag read instead of three barcode reads to be performed at each necessary operation. This will:

- Increase yield at each operation by avoiding failures due to unsuccessful barcode reads. Assuming equivalent performance of barcode readers and RF tag readers, the yield fallout will be three times less with RF tags by only reading a tag once instead of having to implement three barcode readers to read the three elements of information required.
- Less maintenance. Barcode readers are more sensitive to vibration, focus, and scanner angle than RF read/write tags.

- Writing status bits into the RF tags to aid in proper module routing is possible with RF tags by implementing a write head. Barcodes can only be written at one time without a new (costly) label being placed every time the information is modified.
- RF tags on pallets allow modules to be oriented on a pallet in any manner with barcode labels in any orientation for products. Implementing barcode readers would constrain the pallet design to keeping product labels all in the same relative location.

FUTURE ADDITIONAL PRODUCTS
The proposed palletized system is an infrastructure to allow other products with similar functions to be processed on this assembly process in the future. Different test fixtures could be implemented, testers could be modified to run an additional test program, and additional pallets designed to run another product - relatively low investment compared to facilitating a complete additional assembly process (avoiding cost of new testers and transportation system).

Integration Requirements

The concept of integrated manufacturing encompasses everything from low level connections between machine tools to the development of total business strategies. There are two types of integration, resource-oriented and activity-oriented integration[39]. Resource-oriented integration is concerned essentially with physical entities, including computer and network integration, equipment integration, facilities integration, and materials integration. Activity-oriented integration is concerned more with the processes which occur in business, including process integration, information integration, decision-tool integration. This section of the proposal will detail the resource-integration needs of the process and layout design. It includes lessons learned from previous new product launches at NPEF and how these concerns will be addressed in the proposed process. Note that the ramifications for poor integration many times result in intangible as well as tangible deficiencies.

If two companies implement exactly the same technical improvements in their factories and one achieves far superior performance, what are the reasons for this difference? Usually this can be attributed to the amount of attention paid to the people and the systems.[40]The following principles have and been incorporated in the development of this assembly process, and should be considered when planning any manufacturing process:

REJECT HANDLING (FALLOUT AND REINTRODUCTION)
Rejects will be made on every production line, so there must be a plan to react to these rejects. The result of this analysis may determine that all rejects should be scrapped if economic justification does not exist to spend time to repair a reject. However, in the automotive electronic systems manufacture, this usually means creating a plan to repair and reintroduce the modules back into the process.

The DDM/DSM line will reject all test failures and bad reads before the pack operation (at the pallet status check) onto a long reject lane. Troubleshooters may come and remove the modules from the pallets, retest them, remove the housing (and keyfobs for the DDM) and place them at the keyfob mate-load station, troubleshoot and repair the circuit boards, and return the repaired boards to the keyfob mate-load station. This guarantees the integrity of the keyfob matching with DDMs by requiring all rejects to go back through the keyfob mate station. Housings will require the end-item label to be removed, invalidated, or ignored with a new label placed over top.

All rejects routed onto a single, long reject lane allows operators to easily go and collect the rejected modules and minimize wasted time and motion of running to each tester for individual reject buckets. The number of rejects is easily seen by looking at the one reject lane, making it obvious when the process is having a significant quality problem.

Repairability of modules must also be considered, referring to the ease which a failed part may be repaired and put back into service.[41] This also includes how to handle incoming material with poor quality. What procedures will you implement to determine poor incoming quality parts if there is a high risk. This is especially important if certain components used in the past have a history of quality issues and there is no alternative quality supplier.

OPTIMIZING OPERATIONS BETWEEN MANUAL AND AUTOMATIC PROCESSES
As discussed in the section above on flexibility, man and machine must be assigned tasks that are most economical, taking strengths and weaknesses of both into consideration when task planning. On the DDM/DSM final assembly line, operators at the keyfob mate-pallet load station locate keyfobs and modules on the pallets since the components are in bags and not easy for a robot to orient, grasp, and place properly. Automation loads and unloads testers and repeatably routes good and bad modules to their proper location (reject lane or pack area), avoiding the possibility of a mistake from a human operator by putting a reject where a passing module should be.

LINE BALANCING
The line should have allocated cycle times in every process to make the cycle times in the assembly process as similar as possible (this does not necessarily make a machine slower to balance it with other machine cycle times). This will allow a "heartbeat" through the line, minimizing process variation, minimizing wasteful work-in-process (WIP), and allowing quick detection of problems (due to relatively small buffers). The DDM/DSM processes should all be close to 13 seconds. This was facilitated by adding the number of testers as required to keep pace with the rest of the line and allocating processes between manual and automatic operations.

MAXIMIZE CAPACITY
At the same time considering line balancing, attempt should be made to maximize capacity at each station. This will allow optimal utilization of facilities as well as allowing stations to "catch up" to the rest of the line after recovering from a fault or processing work that is reintroduced in front of it for an exceptional reason. Although the required line rate is below 250 modules per hour, on the DDM/DSM line effort has been made to easily allow the line to run at 300 modules per hour. Of course, as soon as the line has been launched, upper management will begin asking how the line can manufacture more units per hour.

SIMPLE INTERFACES
Interfaces are the most likely point of failure. This includes many possible interfaces: modules to processing fixtures such as final test, line controller conveyor communication with station controllers, line control interfaces to upper level CIM database applications, or product interfaces between different materials such as a fiberglass board and a polypropylene housing. At such interfaces, unforeseen states may cause confusion between two systems resulting in an "out-of-synch" condition, unforeseen tolerance stack-ups may cause a bad fit, protocol differences in error states or default restart conditions may cause confusion in equipment. Each interface should be thought of, and simplified to insure the most robust system (remember the acronym "KISS" - Keep It Simple Stupid).

In the DDM/DSM line, interface between the conveyor and line controller has been simplified by requiring the tester manufacturer to be in control of all the conveyor controls to lift and locate a unit for test. This will allow the manufacturer to take a section of conveyor and debug the complete test system off-site and prevent any finger pointing between the integrator of the line and integrator of the tester when parts are not being tested properly. The DDM and DSM modules have had features added to the housing to allow the closing of the housings to be easier and more repeatable.

FUTURE EXPANSION
Thought should be given as to future requirements for increased capacity. At the planning stage it is easy to put in place options allowing future expansion. For example, the DDM/DSM final assembly line has space reserved for two additional functional testers to be modularly placed on the line. Not only is expansion space required, but expansion planning should allow for short starting up time of the additional systems and the possibility to improve capacity without stopping the existing operation.[42]

HUMAN FACTORS
Human factors must be considered, such as ease of maintenance, ease of moving around equipment, ease of getting to reject chutes, etc. On the DDM/DSM proposed layout there is one operator at each end of the line to monitor the machines in their respective zones. Testers have been positioned with fixtures facing outward for ease of periodic maintenance required.

MINIMAL CHANGEOVER TIME
Processes should have minimal changeover and setup times to keep the line running as much as possible. This also minimizes the negative impact of production scheduling changes driven by changing customer demand on the process.

Although run in a batch mode since units will generally come in batches from upstream, all processes will be automatic changeover on RFID tag reads for zero time changeovers. For example, the testers will read the pallet RFID tag and then automatically use the required specific test program and limit data tables stored in memory and on hard disk to test the module accordingly.

ERROR DETECTION AND FAULT RECOVERY
As manufacturing systems become more automated and complex, there is a need for supervisory control systems to operate and control production in an adaptive manner. The future manufacturing systems will demand error-free operation incorporating both error detection and recovery capabilities. Automatic error recovery is an essential feature and directly relates to the development of unattended manufacturing systems. Studies have shown that conventional manufacturing only makes use of about 18 per cent of the capital investment in machine tools, and the rest of the time is related to non-value adding activities, including unplanned downtime. This seems to indicate that there is a great potential in manufacturing systems for increases in efficiency, productivity and profitability in manufacturing systems if more efficient error recovery mechanisms are incorporated.[43]

The error recovery process consists of three major activities:
- Detection. The error state has to be recognized by the system in order to take the necessary action.
- Diagnosis. The data from the detection phase is used to identify the problem.
- Recovery. Planning the recovery action and selecting and implementing the most appropriate action rapidly and safely.

Traditionally, only functional properties are considered for the specification and design of manufacturing systems. If non-functional properties like fault tolerance and error recovery were considered at all, this typically happens only during the implementation phase. Practice, however, shows that there is a strong relation between these properties and system architecture. In order to cope with the increasing demand for continuous and efficient operation it is important to take non-functional properties such as error recovery into account from the very beginning of manufacturing design and redesign.[44]

Typical problems with manufacturing systems include:[45]
- Physical breakdown of one or more machines because of hardware faults, material faults, unexpected behavior (e.g. because of vibrations), etc.
- Logistics failures like jams in a production loop.
- Inconsistencies between information system states and the physical reality, e.g. because a product falls unnoticed from the line, or because of incorrect measurements and hardware (sensors, motors, etc.) failures.
- If a failure occurs, sometimes the whole assembly line must be reset and restarted.
- The implementation of local error detection and error recovery procedures is not possible because of the lack of additional sensors and actuators.

One way to provide for fault tolerance is to install extra sensors in buffers and pushers to enable error detection and know the state of parts, or leave extra inputs and outputs (I/O) on the assembly line for adding sensors and stops to the line for unforeseen problems. These steps will be taken on the DDM-DSM final assembly process, as well as designing in manual stepping functions for debugging problems and implementing reset mechanisms to return control systems to a beginning state without damaging any elements of the system.

AVOID SINGLE POINTS OF FAILURE

Processes will stop for a variety of reasons, as indicated above. Implementing parallel stations minimizes the production impact from cells that are in error. Instead of stopping the whole production flow, it is reduced. For example, output drops to 50% when one of two parallel stations is faulted, instead of 100%. This principle can be implemented with parallel cells, redundant feeders, or having alternative backup processes (such as manual operations that can be implemented when a robot is inoperative, for example). The DDM/DSM line has parallel testing operations and space for additional labelers to be added on-line in parallel if the labeler downtime becomes significant.

UNDERSTAND AND PLANNING FOR CONSTRAINT (OPTIMAL BUFFERS)

Eli Goldrat says it best with this image of boyscouts hiking in a line through the forest, analogous to a production line:

> "The plan, I learn, is for the troop to hike through the forest... Five or six more come along, all of them keeping up without any problems. Then there is a gap, followed by a couple more scouts. After them, another, even larger gap has occurred. I look down the trail. And I see this fat kid. He already looks a little winded. Behind him is the rest of the troop... Herbie continues up the trail and the others follow. Some of them look as if they'd go faster, but they can't get around Herbie."[46]

Effort should be taken to balance the assembly process as well as possible, so all operations take the same amount of cycle time. Naturally, certain processes will be slower than the others. Provisions must be made for these stations with buffers, to insure that the constraint operation always has parts to process while it is running, and insuring that the station is not blocked by upstream operations. Determine what stations are most likely to be "Herbies" and plan around them.

In the DDM-DSM final assembly process the testers are most likely to take longer than their planned cycle time. Buffers on the incoming tester lanes will be implemented to always have product ready to go into the tester. Buffers on the tester output lanes will insure that a delay in offloading the product from the tester spur onto the main conveyor transport will not prevent units from being released from the tester.

MISTAKE-PROOFING

The Japanese word "poke-yoke" literally means "fool-proof". Wherever possible, processes should be fool-proof, not allowing processes to be performed incorrectly jeopardizing product quality or result in harm to people or processing equipment. This can be as simple as a post preventing a module from being seated incorrectly, or a sensor that insures that required components have actually been assembled by detecting the presence or non-presence of the component. The process should be analyzed to insure that any potential mistakes that a person or machine can make will be immediately automatically detected and automatically resolve the situation or notify personnel that action is required. This is an on-going process, and when errors happen on the assembly line poke-yokes should be added to prevent the error from happening again. This final assembly line will have sensors to insure that the housings of DDM and DSM modules are properly closed and methods to insure that the proper keyfobs have been mated with the proper DDM.

LAUNCH WITH BOOKSHELVED TECHNOLOGIES

Many risks need to be managed to complete an integration project on time, within budget with all the features required. Increasing the risk of not completing the project successfully will be increased exponentially if there is an attempt to integrate processes that have not been proven in a production scenario. Said another way, the focus here should be on implementing proven technology that can deliver 75 percent of the benefits in 25 percent of the time at 25 percent of the cost.[47]

Most of the DDM/DSM final assembly processes are performed currently throughout the plant. The Ford Markham electronics facility currently manufactures a DDM module with similar RKE features and tests RF performance and Motorola currently manufactures the current DSM. Significant differences to note are that the current DDM is made in a very manual process and programming of the keyfob TICs into the DDM is done by manually pressing the keyfob buttons. In order to automate this and realize savings in labor cost, NPEF will implement a more automated process which programs the DDM after obtaining the TICs from keyfob barcodes and downloading them to the DDM via electronic messages to the modules. Driving processes by barcode is done frequently throughout the plant so this should be considered a proven technology.

PROJECT MANAGEMENT

The best technical solution will fail without adequate planning and management of a project. Project management Includes:

- managing the technical issues and other risks to resolution
- preparing plans to accomplish all tasks
- insuring program timing is on target
- insuring that people are performing the required tasks according to a predetermined schedule
- insure communication between all the required groups is taking place
- insure all parties have clear expectations (includes functional specifications, discussions)

Detailed timing has been determined for implementation of the proposed DDM/DSM final assembly process, as well as continual meetings and discussions with all related departments.

SEMI-AUTOMATED AND RAMPED LAUNCH PLAN

A semi-automated launch should be considered to identify any processing, material, or design flaws in the production process before investing in large amounts of automation that may not be effective due to unforeseen problems. Ramping up to required production rates over a specific time period will also allow the system to be "debugged" before every minute of uptime is critical, allowing time to identify and permanently resolve any and all issues. The DDM/DSM line will be launched in a ramp-up manner, roughly from half of full production volumes to full production volumes at the end of six months.

It is also important to note that products with no clear quantifiable market demand should be assembled manually at the outset. Here the correct choice of manual assembly organization is important. It must satisfy two requirements:[48]

- The capability of upgrading to automaton at a later stage.
- Should upgrading be delayed or not possible, the system must be as efficient as possible.

Such machinery must be capable of being upgraded to a higher level of automation (to be able to produce in higher volumes in the future with minimal investment).[49]

STANDARDIZATION - MINIMIZING CUSTOM SOFTWARE AND EQUIPMENT

Wherever possible, hardware equipment and software should be common in the process. Standard methods of programming should be used, software versions should be the same, similar operating system platforms implemented. This allows people to more quickly troubleshoot and determine the cause of equipment problems thus increasing up-time of the system. The commonization should span across the whole assembly line as well as the whole manufacturing facility, allowing people to rotate into different areas with minimal training.

DISPLAYING INFORMATION

In a well-managed factory, problems are exposed quickly so that corrective action can be taken. It is important to understand how the process is running in an immediate and quantifiable manner. Information that is required at each process step to perform the process should be easily available to the operators or machines. For example, large LED display panels can be used for error reporting, giving a descriptive error message to an operator on what is exactly wrong with a machine.

Andon means "lantern" in Japanese. Just as a lantern may guide people walking in the dark, an andon light helps expose abnormal conditions in the factory.[50] Sometimes these lights are green, yellow, and red lights (GYR lights) stacked on top of each other to signal the status of a station - green means the station is running fine, red means the station is faulted, and yellow may mean that parts are getting low. . Because of an emphasis on visual methods for quick information transfer, the practice is called "management by sight" or "visual control".

The DDM/DSM process will have an operator interface at the keyfob mating station to allow the operator to quickly see whether the proper keyfobs and DDM module have been mated. GYR lights will be at every station.

INTERFACING, AUTHORITY AND INTERACTION OF SYSTEMS UNDERSTOOD
Control systems must be well-thought out so that development and implementation is successful as well as troubleshooting when future problems appear. Architecture choices should be chosen in a logical manner. Block diagrams need to detail how stations interact and the sequence of events between two stations. For example, on the DDM-DSM line, serial interfaces between the PLC line controller and stations (including RFID tag readers and barcode readers) will be avoided by implementing cards that can plug right into the PLC backplane (making data available to the PLC program without manipulations of an interface program) to simplify control architecture. Sequence of events and signals have also been defined for interfacing the functional testers to the line.

COMBINING OPERATIONS
Whenever possible, combine operations to simplify the process. This must be done intelligently to insure that the process is not made unreasonably complex. The DDM-DSM final assembly process has combined the kit label placement (to identify the Ford part number for the DDM-keyfob kit) and tape (used to secure the keyfobs to the DDM module) currently used in the process at another Ford facility. Tape will be dispensed that will contain all the kit label information printed on its face, essentially eliminating one step in the kitting operation.

QUALITY OF COMPONENT PARTS AND SUPPLIER RESPONSIVENESS
Thought must be invested into the possibility and probability of material suppliers sending in defective products. The impact to the line must be examined, and the ability to place necessary inspection screens in place must be present. Small areas of space should be left on the line for future implementation of poke yoke (fool proof) sensors to be added upon realization of an unforeseen issue.

On the DDM-DSM line the greatest concern lies with keyfobs that will be matched to the DDM modules. A history of quality problems forces extra precaution for the first six months of production, testing keyfobs off-line in an incoming inspection which will be removed six months after launch. After this preliminary six months, clear expectations have been communicated that if a keyfob issue is found the supplier will be forced to test the keyfobs onsite until the quality issue is resolved, using the same equipment used in the six month launch period.

PREVENTIVE MAINTENANCE
Often overlooked, the line must be optimal to allow tradesmen and operators to easily reach where they need to clear a jammed part or easily reset a machine. Spare wires should be run when laying down input and output cables from the PLC to require minimal work when an incremental improvement (such as a sensor needing to be added to prevent a jam) needs to be implemented in the future. Cross-functional teams of skilled trades and engineers in the initial design and review of the DDM-DSM line have and will continue to insure that the layout does not compromise ease of maintenance or safety.

EASE OF SOFTWARE DEVELOPMENT
Hardware and software standards must be developed and maintained. Similar control systems must be used across the specific assembly line as well as across a whole facility to insure familiarity and ease of software development and modifications, as well as troubleshooting systems. The DDM-DSM line will be controlled with a main line controlling PLC similar to hundreds throughout the plant, an Allen-Bradley PLC5. Individual stations will use applications that can be bought off the shelf, such as Microsoft Visual Basic, to enable a larger number of people to be able to maintain the systems.

SCOPE OF OPERATOR RESPONSIBILITY
Thought must be given to placement of people on the assembly line. Their scope of responsibility must be determined, balanced, and it must be a reasonable area for an operator or skilled tradesperson to cover adequately. On the DDM-DSM line the processes have been designed to have an operator at the beginning

and end of the process, allowing them to cover only half of the process. Crossover stairways will not be necessary, and the line is not one long line that cannot be passed through, but a loop that can be walked around relatively easily.

PLAN FOR EXCEPTIONS
Note that many of the above principles are basically noting that a process must be prepared to handle not the typical, but the exceptional situations - the units that fail test, the time that processes fault and do not run properly, the times different products must be run, installing timing being delayed, etc. The manufacturing engineer must plan for these inevitable exceptions to build the most robust assembly process.

Detailed Station Specifications

Specific requirements for each station describe general purpose of station as well as the specific details of how the station should function.

Line and station detail

1.0 Line Controller

The line controller will be an Allen Bradley PLC5 for all I/O, stops, routing, routing decisions, etc. Allen-Bradley PLC5s are used extensively throughout the plant and leverage experience with both hardware and software as well as spare parts inventories. There shall be a main control panel with a line cycle stop, reset for conveyor faults, conveyor start and stop, a message display for faults and line status, and a GYR tree above it indicating the status of the line. Each I/O card shall be for one and only one station (including conveyor controls for that station). The line controller will control all routing and be optimized for throughput. Stations that are offline (in manual mode or faulted) will not get fed any more units and units will go to other parallel station where existing.

There must be counters and timers to collect data from each station controlled by the line controller (good, bad, total, number of specific faults, etc.). Memory map of the counters and timers must be completed as per General Equipment Specification NP-025 in section L (NPEF CIM Application format and protocol specifications).

2.0 General Requirements for All Stations

All stations are to have an auto mode and a manual mode. In manual mode, an operator can manually cycle the station by individual process steps. This also allows the operator to manually cycle the machine after clearing a fault condition and return the station to a home position for return to auto mode.
Steps out of sequence that can cause damage to product or equipment must not be allowed in manual mode.

All E-stops must be placed above knee-level in easily accessible locations, and locations where the chance of accidental activation is minimal. Start buttons should be shielded and stop buttons non-shielded.

A machine status light (GYR tree) indicating station status shall be provided on all stations with green indicating running in auto mode, yellow indicating in manual mode offline, flashing yellow with green is low on parts, and flashing red (no other lights should be on) indicates a fault condition.

All stations and controls must be designed to facilitate easy, logical troubleshooting of the systems and ease of maintenance procedures.

Model information of units required for routing or processing can be obtained by reading a barcode on a unit that will have a 2 or 3 character model key in it to determine processing requirements.

3.0 Conveyors - General

The conveyors are to be Bosch pallet transfer conveyors from the EDIS line. Conveyors will stack up no more then 5 pallets back to back.

Units will be singulated through nodes and the next unit held until the first unit is sensed clear of the node. If the first unit does not clear after a certain amount of time, a node fault will occur and the next unit will not be released until reset at the main control panel. Sections of conveyor around manual station shall have a plate in the center to keep units from being dropped between conveyors and allowing units to be place on the conveyor correctly.

4.0 Pallets - General

Pallet design goal is to have one pallet to hold either the DDM or DSM module. Pallets will have RF tags in them to hold the following information:

Description
Keyfob #1 (24 characters maximum)
Keyfob #2 (24 characters maximum)
DDM Serial Number (24 characters maximum)
DDM End Item Label (24 characters maximum)
DDM Kit Part Number (24 characters maximum)
Pallet Status Bytes (6 Bytes)

The RF tags will be implemented to allow flexibility in the assembly process, keep the information about the units on the pallet so three barcodes do not have to be scanned at each cell. An alternative approach is to have an N-File lookup table in the PLC that keeps information on the binary pallet code

Note that the height of the DSM and the DDM modules (the flat part of the DDM) must be the same level and must be in the same spot for the final end item label and the height poka yoke sensor.

The general format for the status byte will be:
StationAProcessed|StationAPass|StationBProcessed|StationBPassed...

A high bit will signify that the station processed a pallet and that it passed. For example, the status byte 00111011 would signify that the pallet was not processed in station A and of course did not pass the process (00), station B processed the pallet with a successful passing status, station C processed the pallet but it failed, and station D successfully processed the pallet with passing status.

5.0 Keyfob Mating Station - Assembly on Pallet

At the beginning of the shift and whenever necessary the operator uses an interface (a Visual Basic program running on a PC) to input what DDM-keyfob kit or DSM module needs to be built next (schedules that the next kits should be a specific end item kit part number). One operator will be at this station.

The scheduler should display a list of the possible combinations of DDM module (Ford module part number) and keyfobs (family, frequency, and protocol information on keyfob barcode), and the resulting keyfob kit. Note that either two or no keyfobs will be mated with every DDM module. In the following descriptions the two keyfobs will be referred to as the first and second keyfob.

At this station the following happens in each DDM cycle:

a. Operator picks up first keyfob
b. Operator places first keyfob into pallet and barcode scanner is triggered to read barcode
c. PC sends move-in to CIM for validation on first keyfob passing incoming keyfob tester
d. Operator picks up first keyfob
e. Operator places first keyfob into pallet and barcode scanner is triggered to read barcode

f. PC sends move-in to CIM for validation on second keyfob passing incoming keyfob tester
g. PC verifies that first and second keyfobs are the same type and the kit scheduled
h. Operator picks up DDM PWB
i. Operator scans PWB barcode
j. Operator places PWB in DDM housing
k. Operator closes DDM housing
l. Operator places housing-PWB assembly on pallet
m. Operator presses palm button
n. PC scans keyfob barcodes and verifies that they are the ones read in steps b and e
o. PC writes information to RF tag on the pallet (see 3.2.3.B for pallet information)
p. PC sends a moveout related to the DDM module on the pallet

Throughout the process, if any of the matching or validating is incorrect, the PC displays a clear message telling the operator what is wrong with the mating of the keyfobs to DDM.

PC Display should include the following:

- Indicator each for first fob, second fob, and DDM:
  Green Barcode read and is correct type
  Red Barcode read and incorrect match
  Yellow Barcode not read yet
- Required keyfob for the chosen kit (possibly showing bitmap image of fob) frequency and style
- Required DDM module type for the chosen kit

PC controls verify:

- Correct mate of keyfob type to DDM model (from DDM-keyfob table in PC)
- Both keyfobs are identical
- Correct keyfob-DDM kit is being mated according to initial scheduling decision (described above)

PC Inputs and Outputs:

- Serial line to trigger and input first fob barcode reader
- Serial line to trigger and input second fob barcode reader
- Serial line to trigger and input PWB barcode reader
- RF Tag interface card and hardware to write to pallet RF tag
- Output to PLC to tell PLC to take pallet away
- Input to PC when palm button pressed
- Ethernet connection to do validation

At this station the following happens in each DSM cycle:
a. Operator picks up DSM PWB
b. Operator scans PWB barcode
c. Operator places PWB in DSM housing
d. Operator closes DDM housing
e. Operator places housing-PWB assembly on pallet
f. Operator presses palm button
g. PC scans keyfob barcodes and verifies that they are the ones read in steps b and e
h. PC writes information to RF tag on the pallet (see 3.2.3.B for pallet info)
i. PC sends a moveout related to the DDM module on the pallet

This cell is rather complex, and as one team member stated, "This is going to be exciting." A preliminary station will be developed offline and tested out to debug and evaluate the station design before implementation. An experienced Visual Basic contractor may be contracted to complete the programming of this station.

Note that to increase the speed of this station when loading DDM modules and keyfobs another operator can pre-stage the keyfobs and housings on the pallet prior to the return pallets reaching the keyfob mate operator. This essentially divides the tasks in half among two people to insure that the required cycle times are met and can allow the future capacity of this station to increase.

6.0 Automatic Housing Close Station (if required)

The Keyfob Mating - Assembly on Pallet station (above) requires a significant number of steps within a rather small cycle time (13 seconds) when processing DDMs. Time studies have shown that the operation will take close to the target cycle time. Lift and locate mechanisms for a pallet will be installed here to allow the ease of installation of an automatic housing close mechanism if required (to offload some work from the keyfob mate operator).

Note that the DSM module takes considerably less time to process than the DDM module at the keyfob mate - assembly to pallet process, so this station could be simplified to only close DDM housings.

7.0 Housing Poka yoke Station

A 100% height sense poka yoke device will insure that all housings are closed. This will also verify that no modules have the wrong housing by sensing whether a hole, housing, or connector is present. Holes that are not filled with a connector will fault and stop the line because the operator is not loading the correct housings at the keyfob mate - assembly to pallet station.

8.0 End-item Label Print and Apply Station

Every DDM and DSM must have an end-item label on it, telling what model, Ford part number, and serial number it is. This information will be used in the pack operation as well as at the customer sites. For the line to be flexible, these labels must be printed “on-the-fly”, with lot size one. In order to do this either the line controller or label applicator controller will read the pallet RFID tag to determine what module is on the pallet, and then print and apply the label accordingly.

9.0 Final functional test stations and routing

Testers and connector interfaces to modules will be manufactured by a tester manufacturer - not in-house. The final assembly automation must route modules to the four testers (optimized for throughput in a parallel manner), lift and locate the units for testing. The line is to present a unit to a tester and use simple discrete I/O (defined later) to the tester to start the test and know when to release the unit. The line will also get I/O from the tester indicating its status for the GYR tree. Additional conveyor length is available to allow the addition of testers to the line in the future.

Testers will read what module serial number and model type from the RFID tag on the pallet and automatically test for the specific model type by pulling up the correct limit files and test code. Testing will verify the functionality of the DDM and DSM modules. DDM modules ability to receive and decode a weak RF signal from a keyfob will also be verified as one of the tests. This RF sensitivity test will use a keyfob signal generated by the test sets and requiring an RF-tight enclosure to accurately determine RF receiving ability without noise from the outside world.

Two nests will be in front of the testers, one with associated connectors for the DSM module and one with the RF enclosure for the DDM module.

After a module is tested, a message will be sent up to the Ford supervisory CIM system denoting whether the specific module passed or failed testing, and if it failed which tests failed at what measured value. This will allow reports to be generated to determine what problems the modules are having, and then use this feedback to then improve the process. The message sent to the CIM database on pass or fail will also be used at the CIM Gate Station detailed later on.

10.0 RF Label Apply

A preprinted RF label goes on all DDM modules. A sensor determines whether module is DSM or DDM. If it is a DDM, then the preprinted RF label is placed on sloping part of the DDM module. This RF information is required in every country, similar to the FCC requirements in the United States.

Current design assumptions call for one RF label for all DDM modules regardless of operating frequency (country of use). This will allow the labels to be pre-printed so the labels only need to be applied, not printed.

11.0 CIM Gate

After final test, all units (good and bad) will go to this “gate”. This gate (programmed in the line controller) will verify the unit pass previous process points and final test by reading the pallet status bits to determine whether the module on the pallet passed testing, labelling, and the closing operation. If it has, then the line controller will then read the module serial number from the pallet RFID tag to obtain the module serial number information to also verify it passed test via the Fords supervisory data base. The gate will then route the pallet accordingly. Good units will go to the sort and pack operations and bad units will be routed to the reject conveyor, one conveyor that will hold all the line rejects. Operators will thus only have to go to one spot to obtain all the failures and take them to the troubleshoot and repair operation. Circuit boards will be removed from the housing, the housings will be reintroduced at the Keyfob Mate Assemble Board to Housing Station. The old label that is still on the housing will just have a new label placed over it.

The line will have a switch that will turn off the requests to gate on the Ford database. Thus if the Ford CIM supervisory system is down for whatever reason (cable cut, UNIX machine down, etc.) the line will still route good and bad units properly on the pallet status bits alone.

12.0 Sort

Units will be sorted into lanes based on model type. The station will only send one model at a time to the label station. The sort station should consist of 5 lanes and hold 20 units (pallets) per lane. Lanes will be dedicated to model types dynamically, and an interface will allow the kit-pack operator to choose which model types to run down the line. The sort system will only release types that are requested.

13.0 Kit Station - Label Print/Apply

Here is where the keyfobs will be attached to the DDM and a kit label will be generated. The pallet will stop and the RFID tag will be read. If the module is a DSM then it will just pass through to the pack station. If the module is a DDM then barcode readers will also read the keyfobs and DDM module barcode. If the keyfobs and DDM match the information in the pallet then that means that no one has switched the modules anywhere in the process and the programming and testing of the kit has been done properly.

When the information is verified to match, a kit label will be printed. An operator will take the kit label and tape the keyfobs to the DDM module. If there are no keyfobs, no kit label will be generated and the pallet will be released to the next operation If the keyfobs and DDM do not match the pallet a red warning light will go off and the pack operation conveyors will stop. This means that someone upstream has been switching DDMs and keyfobs on and off pallets improperly in the process and that some could be programmed improperly and will not work in the field.

One operator will be at this location when DDM modules are run to kit the keyfobs to the modules.

14.0 Bracket

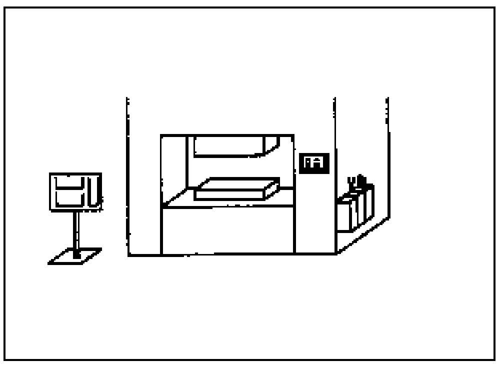
One operator will be at this station when DDM modules are run that require a bracket. Modules will have one character in the barcode denoting whether and what type bracket they receive. After the sort station the line controller will stop and read the module serial number from the pallet RFID tag and stop the pallet if the module requires a bracket. A semi-automated bracketing station will allow an operator to pick up the module with keyfobs attached, place the DDM-keyfob kit on the bracketing tooling with the bracket, press palm buttons which will allow torque controlled screwguns to attach the bracket to the DDM. Bracketed modules will be placed on a table between the Pack station and the Bracket Station since the physical form will not facilitate movement on the pallet. Modules that do not get a bracket will pass by on the conveyor to the Pack operator.

When a module is bracketed properly, a message to the CIM supervisory system will be generated. Later this will be checked to insure that modules requiring a bracket receive them properly in this operation.

15.0 Pack
One operator will be present at this station to take DDMs or DSMs off pallets or from the bracket table and place them into a box. A Ford system will be used to scan each module barcode to insure they are all of the same model type and that the module has passed all required operations (by doing another check to the CIM database insuring the bracket operation was performed if required for that model). Only after all modules in the box are scanned is a box label generated. This prevents boxes with mixed product types and the correct label printed and placed on a box for the customer.

Software Backup Requirements

Two sets of source code for all software on the line with good comments must be on 3.5" floppy disk for backups. Similar to the way that tools should be stored near the point of use and need, software backup disks should also (see figure 14. below).



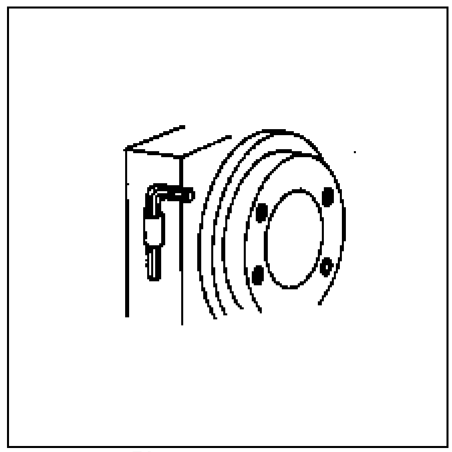


Figure 14. Examples showing required tools near point of use.[51]

Preferred Suppliers

The following equipment should be used for standardization:

Equipment	Supplier
Barcode readers	Datalogic or Accusort Systems
Programmable Controllers	Allen Bradley
Personal Computers	IBM

Timing: Implementation Plan

The EDIS equipment that will be reused will be available in early December. It will be physically removed from the EDIS area before Christmas and staged in an area near its permanent location. Exact wiring diagrams and exact system architecture will be determined before Christmas, with the actual installation and programming of the line in early 1997. The line should be completely assembled and ready except for the final testers which are coming from a third party by April, 1997.

Risks

This is the first project of its kind in the North Penn Electronics Facility, completely designed and integrated in-house. It is important to be aware of the risks that could compromise the timing, budget and success of the project:

- Internal organizations may respond too slowly, not accustomed to doing such a large job in-house.
- Engineers in control do not have adequate documentation of the wiring, controls, etc. due to their inexperience with such requirements or lack of resources. This could hinder future understanding of the process when needed for troubleshooting, etc.
- Expanding keyfob complexity. Keyfob types will continue to expand endlessly, adding complexity to the process.
- Understanding of RF electronics. The DDM is the first RF module in the plant. New experience will need to be gained to become adept at diagnosing modules failures and faults in equipment related to RF issues.

Conclusion

Companies intent on improving their manufacturing and design processes should take a hard look at changing some of their most closely held beliefs, their “sacred cows”. In manufacturing, these sacred cows are the untouchable designs, specifications, processes, and facilities that are cherished most. Sacred cows are easy to identify: simply question aspects of a design until you hear it vehemently defended by someone insisting "We've always done it this way" "This is the essence of our product!" ... "We can't change this, the boss came up with it" or "We already have too many problems with this. We can't change!" If they say it can't be done, you've found a sacred cow. And sacred cows, although they are the hardest to change, yield the most profit when they are toppled.[52]

In proposing this assembly process, an attempt was made to take a step back and insure that the layout and process meets all requirements with a cost-effective, flexible, robust method. In a non-traditional blend of manual and automatic processes the line will be completely designed and integrated in the plant instead of involving an outside contractor. Only by thus stretching the reuse of facilities and responding creatively in planning manufacturing processes will Ford's North Penn Electronic Facility be able to survive in the global economy of the twenty-first century.

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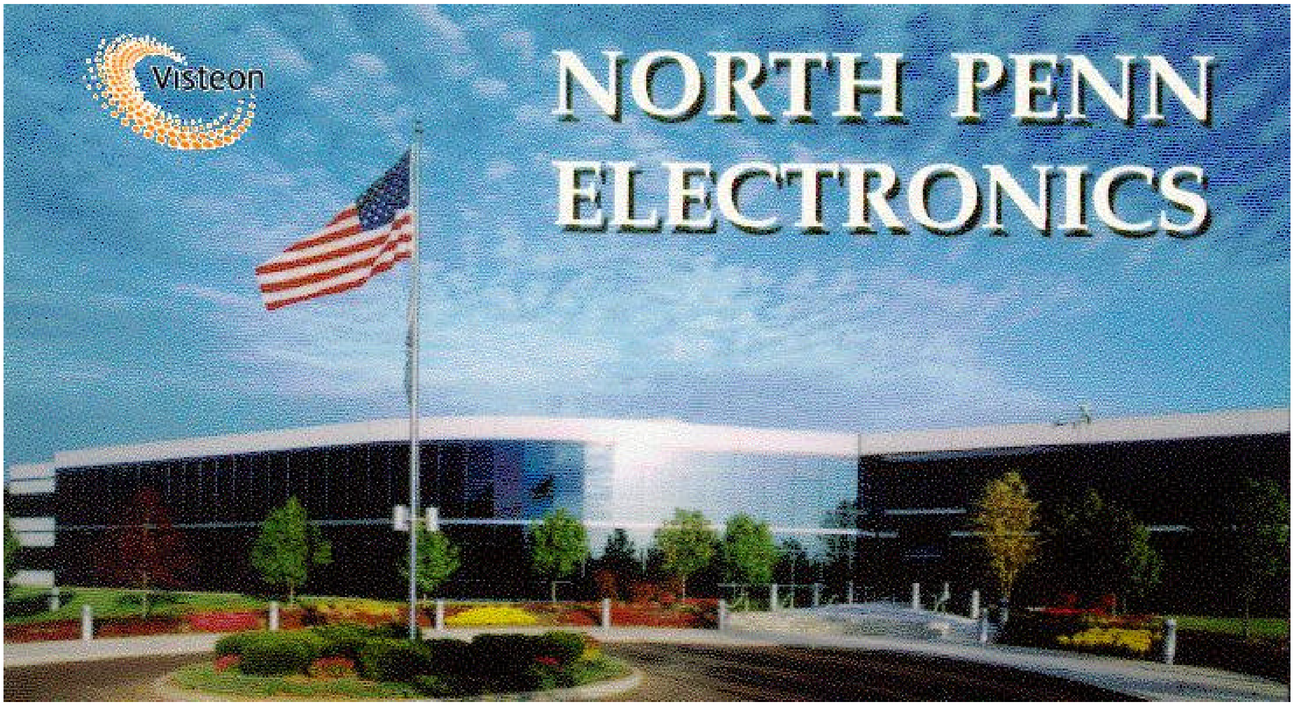

North Penn Electronics Facility
2750 Morris Road, Lansdale, PA 19446 USA, Telephone: 610-584-2400

Overview

Employees: 1650
Year Opened: 1990

Site size: 87 acres
Current plant size: 705,092 sq. ft.
Mfg. Floor Space: 404,000 Sq. Ft.

Products Shipped per day: 100,000
Components Consumed per day: 9 million

Products

Air suspensions, electronic engine controls, mass air flow sensors, speed control amplifiers, temperature sensors, anit-lock braking systems, pressure sensors, electric vehicle electronics, distributed power electronics.

Customers

Ford North American assembly plants and engine plants, Ford Europe, seven Visteon plants, Jaguar, Toyota, Nissan, Mazda. Annual production: 38,127,484 units.

Awards

- Industry Week magazine's "10 Best Plants in America"
- Shingo Prize for Excellence in Manufacturing, 1996
- Ben Franklin Technology Award for Manufacturing Excellence, 1996
- Ford Automotive Components Division Complexity Reduction Award, 1995
- ISO 9000 Certification
- Ford Q1 Certification and Total Quality Excellence Award

Technology

Capabilities include state-of-the-art surface mount techniques, lamination for heat transfer, low temp. co-fired cermaics, and thick film/ceramic substrates. New products combine technologies for high-power electronics. Pressure sensors have been added to the plant product line, along with electric vehicle and commercial powertrain control electronics.