# A Design Methodology for Automotive Component Manufacturing Systems

by
**Brian Klippel**

B.S. Electrical and Computer Engineering, University of Wisconsin-Madison 1990

Submitted to the Sloan School of Management and the
Department of Electrical Engineering and Computer Science
in partial fulfillment of the requirements for the degrees of

**Master of Business Administration**
**and**
**Master of Science in Electrical Engineering and Computer Science**

in conjunction with the
**Leaders for Manufacturing Program**

at the
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Abstract

This thesis proposes a design methodology for manufacturing processes in automotive component plants. Included is a proposed set of analysis tools to be developed to aid the manufacturing engineer in designing new manufacturing lines. The intended users of this methodology are manufacturing engineers designing or facilitating the design of a new process.

The proposed methodology utilizes Quality Function Deployment to identify the requirements of a new manufacturing line, and to facilitate both a system level and detailed level design of the new process. The methodology is used to develop the new process in terms of the plant, operators, customers, supply chain, product design, and line design requirements. The relationship between the purchasing organization and the equipment suppliers is studied to identify the incentives in the existing purchasing system. This thesis also describes examples of how the methodology can be used, including an application for an electronics assembly line, and three ex-post analyses to show the benefits of a structured methodology.

In an increasingly competitive environment, the use of a structured methodology can help an automotive supplier to develop more efficient processes while bringing products to market in less time. The use of analysis tools facilitates the design process, allowing manufacturing engineers to make better decisions faster.

Thesis supervisors:
Stephen Graves, Professor of Management Science
Daniel Whitney, Senior Research Scientist

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# 1. Introduction

This thesis presents a methodology to conceive, design, and develop manufacturing lines for automotive components manufacturing facilities. This research is the result of a six month project at Ford Motor Company as part of the MIT Leaders for Manufacturing program. The methodology is meant to guide the engineer through the design process, considering the various stakeholders in the manufacturing line. The fundamental concept is to organize the development process to avoid mistakes resulting from informal approaches which are derived from the experience of the engineer rather than a systematic method. This thesis presents a process design methodology and a set of analysis tools to develop new manufacturing processes.

This chapter provides the framework of the thesis, beginning with the background and goals of the research project. The Ford Production System is briefly reviewed, as it is a significant organizational change for the company. Finally, the chapter concludes with an overview of the thesis structure.

## 1.1. Background

This research project was performed in Visteon Automotive Systems' Operations Engineering section of Ford Motor Company. Visteon, an enterprise of Ford Motor Company, is composed of seven divisions: Interior Systems, Exterior Systems, Powertrain Control Systems, Climate Control Systems, Glass Systems, Chassis Systems, and Electronics Systems. As a resource for Visteon's manufacturing operations, the Operations Engineering section performs simulation and optimization projects in support of the manufacturing plants.

### 1.1.1. Scope of Ford Motor Company's Capital Expenditures

In 1996 Ford Motor Company automotive plant and equipment expenditures totaled $8.2 billion (Ford Motor Company, 1997a), making new process development an important part of the automotive business. The success of any process depends on the experience, knowledge, and ability of the manufacturing engineers and the involved team members. To manage this level of annual investment, structured methods are required to consistently implement successful manufacturing lines and to implement new production concepts. Ford is implementing lean manufacturing through its Ford Production System (FPS). FPS provides plant level principles and metrics to achieve more efficient manufacturing operations and is the process behind plant design, operation, and evaluation.

### 1.1.2. Examples of Recently Developed Manufacturing Processes

Examples of process design success can be found in any large manufacturing company. In many cases, teams of experienced manufacturing engineers have considered performance objectives, related them to the process design, and achieved high levels of success. The design of an Anti-lock Braking System (ABS) electronics module line demonstrates this approach. A dedicated cross-functional team designed the ABS module assembly lines, which included the Surface Mount Device (SMD), final assembly and test lines. The team defined the design objectives in terms of quality, first-run capability, batch size, preventive maintenance, cycle time, line replenishment, work in process (WIP), environmental requirements, and flexibility. Design alternatives were developed and then evaluated against the objectives.

The ABS line represents an almost ideal situation in process design. A focused cross-functional team of experienced engineers and specialists developed a line for a well defined application. The experienced team based the design process on objective criteria, avoiding the "this is the way we do it here" attitude.

A design methodology provides two important characteristics (Ulrich and Eppinger, 1993). First, it acts as a checklist to ensure all design steps have been completed. Second, it provides focus on what the design must accomplish, based on the user's needs. As a result, a successful methodology aids in both developing lines and ensuring consistent application of FPS principles.

### 1.1.3. The Market Environment for Visteon

Visteon faces a rapidly changing market environment. The automotive components industry is moving from a large group of component suppliers to a small group of complete system suppliers who provide design, engineering, and research expertise.

The relationship with FAO is creating changes within Visteon. As an independent enterprise, Visteon competes with outside suppliers for business both within and outside of Ford.

This has changed the way new business planning is conducted, both in process design and in profitability analysis. The components operations must now study products in terms of price and profitability rather than costs. This change is driven by having to fund facilities and maintain a positive cash flow.

Developing outside sales will also change the way Visteon develops new processes and manufacturing operations. These new customer applications will be in single vehicle line increments of 50,000 to 300,000 parts per year, significantly lower than the existing multi-application volumes produced today. Entrance into the aftermarket segment represents even smaller volumes for a new process. To maintain operating margins, Visteon must develop low cost processes even faster.

To help meet these needs, the Operations Engineering group is changing its focus from reactive to proactive for major projects with which they are involved. Rather than working to improve existing facilities or designs, the group is becoming involved in the design process, where the leverage is greatest for improvement. However, this requires a different set of analysis methods and tools than has been traditionally used.

## 1.2. Goals of the Research Project

### 1.2.1. Develop a Systematic Design Methodology for Manufacturing Processes

The primary goal of this research was to develop an objective driven methodology for manufacturing process design. The intended users are the manufacturing engineer designing a new process and the Operations Engineering staff facilitating the process.

A design methodology also aids in training new manufacturing engineers. By providing a checklist and ensuring customer needs are considered, a methodology directs design efforts in the most productive direction. To ensure capable processes, this includes considering both process design considerations and established business requirements.

### 1.2.2. Identification of Analysis Tools to Support the Design Methodology

The second goal of this research was to identify a set of analysis and design tools to support manufacturing process design. Existing process analysis tools are optimized for process analysis and not process design, which creates two issues with their use. First, they were developed to analyze complex existing designs and require a high level of expertise and training to use. Second, manufacturing engineers require a tool to provide design direction, while the existing tools provide descriptive results.

### 1.2.3. Development of an Implementation Plan

This project recommends an implementation plan for the methodology and analysis tools. Implementation requires agreement from various departments, since the separate divisions of Visteon each control their own design process. A support group for Visteon's manufacturing divisions, the Operations Engineering section must obtain their cooperation to utilize the new methodology.

An implementation plan for the design tools is also suggested. Tool development, distribution, and technical support systems must all be defined and implemented. The plan also addresses documentation and training for manufacturing engineers.

## 1.3. Overview of the Ford Production System

### 1.3.1. Ford Production System Background

FPS was developed to help Ford Motor Company meet its objectives in being a high quality, low cost producer of automobiles. As stated in the FPS vision,

> It is a worldwide, cohesive system that encompasses and integrates our Manufacturing processes and interrelated Ford Product Development System, Order-to-Delivery, Supply, and Management processes. Its purpose is to develop and institute best practices in the methods we use to work with people, equipment, and materials so our customers receive the greatest value. (Ford Motor Company, 1997b)

In implementation, FPS is seen as the means of achieving lean production throughout Ford's worldwide operations. Included in FPS is a set of principles and associated metrics to measure the progress of a plant in the Ford system.

### 1.3.2. Principles and Metrics

The FPS principles are the basic rules the entire system is based on. The principles define the focus of the entire business system, driving metrics and measurement criteria. The principles are:

- Effective Work Groups
- Zero Waste/Zero Defects
- Aligning Capacity with Market Demand
- Optimizing Production Throughput
- Using Total Cost to Drive Performance

The FPS principles provide the basis for a set of performance measurables for all Ford plants. As FPS is implemented within Visteon, plant management and operators are trained in the program and how it affects each position in the organization. The movement to FPS requires new processes be designed with the principles and metrics in mind to ensure overall system performance.

## 1.4. Thesis Structure

The remainder of this thesis is broken into 5 chapters. Chapter 2 describes the manufacturing development process and defines a set of stakeholders in the new line. It then reviews the relationship Visteon has with its equipment suppliers. Chapter 3 is a description of the proposed methodology for process development, while Chapter 4 describes an initial application and other examples of how the methodology benefits users. Chapter 5 describes an analysis toolset for engineers designing new processes. Finally, Chapter 6 lists conclusions and implementation considerations.

# 2. The Existing Manufacturing Development Process

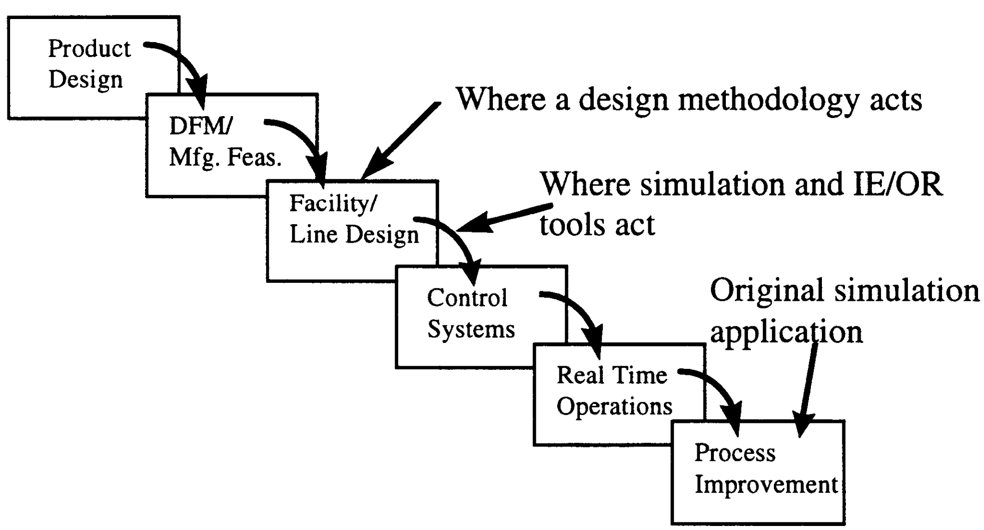
This chapter presents background on the current process of developing manufacturing lines. As an introduction, the existing line development process is overviewed, including the involvement of the Operations Engineering section. The environment faced by Visteon manufacturing engineers and other stakeholders is then discussed. Visteon's relationship with its equipment suppliers is reviewed, as is a set of analysis tools. The chapter concludes with two tools utilized in the new design methodology and a summary of design methodology benefits.

## 2.1. The Roles of Manufacturing Engineers and Operations Engineering

### 2.1.1. The Line Development Process

The existing manufacturing development process is shown in Figure 1, which traces the development process from product design through launch to the process improvement stage.

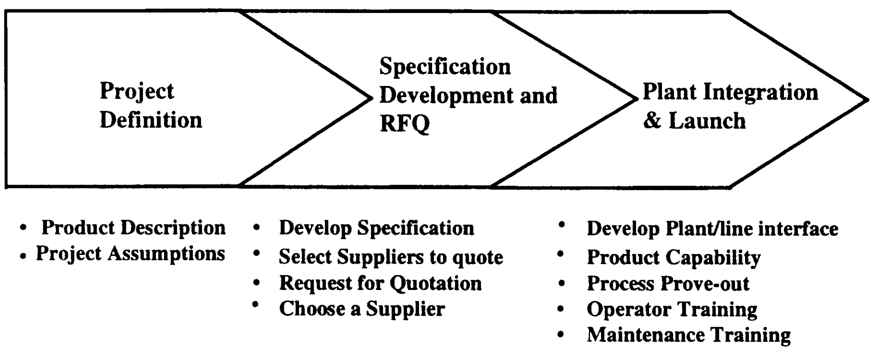
**Figure 1: The Manufacturing Design Process at Visteon**



The manufacturing engineer's involvement begins in product design, where feasibility and other manufacturing considerations are worked into the product design. This role differs by organization, in some cases complete teams are co-located, while in others a single manufacturing representative works in the design engineering area. Manufacturing engineering groups may be divisional staff sections or located at the plant where the line is to be installed. As a result, organizations use different methods to gain product and manufacturing engineering communication from product development through production launch.

The manufacturing engineer's design process then follows a pattern shown in Figure 2:

**Figure 2: Current Manufacturing Engineering Process**




The line design stage begins with the project definition phase, where product volumes, lifecycle, and other business assumptions are listed. By using the business plan and other resources, the Strategic Business Unit or division determines which plant will manufacture the product. The team also determines if the plant or the supplier will complete the integration, the type of line desired, and the requirements for the specification.

The manufacturing engineer then develops the process specification. This document defines a general description of the product and equipment, the standards and compliance requirements, a documentation listing, project management expectations, and process specifications including capacity, reliability, and any known operator or material handling interfaces. The specification becomes the reference document for the quotation, cost, timing, financial and other development issues for the remainder of the project.

For most projects, the manufacturing engineers focus on the Overall Equipment Effectiveness (OEE) measurement. OEE provides a measure of overall system performance, with the FPS objective of OEE > 85% for manufacturing operations. As a result, almost all equipment specifications define performance in terms of OEE. For any machine or system, OEE is calculated by:

$$OEE = (Availablity)(Performance)(Quality)$$

$$OEE = \left(\frac{OperatingTime}{AvailableTime}\right)\left(\frac{IdealCycleTime \times TotalParts}{OperatingTime}\right)\left(\frac{TotalParts - Defects}{TotalParts}\right)$$

Once a specification has been created, the engineer selects the suppliers (basic equipment or system integrators) to provide quotations. The engineer typically selects from a base of familiar suppliers who have previously worked on the product family or with the manufacturing plant in the past. In cases where the plant will be completing the integration, machine builders are chosen to provide quotations. Vendor selection often determines the type of line purchased when system integrators are used, as they usually specialize in one type of assembly or machining system.

After a concept has been selected and a system integrator chosen, the project enters the integration and launch phase. Plant management and operator systems are designed around the chosen concept, including inventory management, scheduling, operator tasks, and maintenance requirements. These control and management systems are bounded by local plant conditions (union agreements, government requirements, etc.) for operator tasks, the plant information system for data gathering, and the existing management structures for shift patterns and other operational issues.

The Operations Engineering section, unlike the manufacturing engineer, has a different role before the launch of a new line. Their specialization in simulation and optimization has their project involvement primarily in the process improvement phase. As simulation has become more accepted, however, the Operations Engineering section has worked with manufacturing engineers to study proposed process designs and find areas of improvement.

## 2.2. The Line Design Environment

This section addresses two topics: the engineer's work environment and the manufacturing engineer's ability to change the business systems affected by a new line design. A set of stakeholders in a new manufacturing line is defined. Addressing work environments defines how analysis tools must work in process design, while the affected systems suggest considerations for the design methodology.

### 2.2.1. Engineering Work Environments

To develop a process design methodology for use by manufacturing engineers and to include analysis tools which are managed by the Operations Engineering section, the differences in the two work environments must be understood. A series of interviews were completed to develop insight into the roles of the two groups.

The Language Processing Method (Center for Quality of Management, 1996), a structured method for understanding language data, was used to study the manufacturing engineer's work environment. As derived from the interview data, manufacturing engineers see themselves as innovators and implementers of new technology. The engineers have the perception that business and financial systems are challenges that must be negotiated with to develop new projects. They face an uncertain environment where project assumptions, management objectives, and product designs are constantly changing regardless of their project's schedule. As a result, the engineers find themselves making difficult decisions in short periods of time, and need rapid analyses of proposed process designs.

In comparison, an Operations Engineering project on an existing process may take up to four months, involving several detailed iterations. The analyst may take a month or more to build a simulation model, where the manufacturing engineer may have to chose a line concept in a week or two. Finally, an Operations Engineering project is focused on one project client, usually a plant, while the manufacturing engineer must consider an entire set of stakeholders. Table 1 summarizes the differences between the groups.

**Table 1: Comparison of Manufacturing and Operations Engineering**

| Manufacturing Engineers | Operations Engineering Analyst |
|---|---|
| Entire system requires definition | Capacity or scheduling based |
| 1-4 week evaluation period | 1-4 month project |
| Plant and product may be uncertain | Well defined product and process |
| Objective is concept validation | Complex, detailed analysis |
| Approximately 1 major project 1-2 years | 3-5 major projects per year |

### 2.2.2. Stakeholders in Process Design

In looking at line design, various authors have listed sets of influencing elements. In the implementation of a Flexible Manufacturing System (FMS), Thomas (1994) found three principal elements driving a new technology decision: corporate control over the fate of the plant, the plant's limited autonomy in choosing technology, and the state of union-management relations. In contrast, Nyman (1992) considers plant departments; including production, product engineering, scheduling control, marketing and sales, the union, human resources, and quality control in describing cell design. For the design of a Visteon process, the engineer must consider six affected stakeholders: customers, plant operations, operators or work teams, product purchased part supply chain, line design, and product design. The customer purchases the products the new line will produce. The plant and operators refer to the facility and people who will run the new line, while the supply chain involves the purchased parts for the line. While line design is the responsibility of the manufacturing engineer, the other stakeholders have business processes in place with which the new line must interface. The ability of the engineer to change each of these business systems is different, as shown in Table 2.

**Table 2: Engineer's Ability to Change Stakeholder's Systems**

| System | Ability to Change |
|---|---|
| Customer | Low |
| Line Design | High |
| Plant Operations | Medium |
| Work Teams | Medium |
| Supply Chain | Medium/Low |
| Product Design | Medium/Low |

## 2.3. Visteon's Relationship with System Integrators

### 2.3.1. The Equipment Purchasing Process

In general, Visteon outsources the design and manufacture of its manufacturing equipment to system integrators and/or machine builders. The level of integration that suppliers provide ranges from off-the-shelf standard machines to entire manufacturing systems. In some cases, the system integrator designs the system, chooses the machine builders, purchases material handling equipment, develops control systems, and integrates the line. The relationship is based on the Visteon engineer's recognition that the suppliers add value with their expertise and creativity, and develop the best line for the particular situation.

When purchasing a manufacturing line, the Visteon engineers specify the major manufacturing, assembly, and test sub-systems for the vendors to quote. For example, when purchasing a new component process, the engineers broke the line into three sections, armature manufacturing, assembly, and test. The engineers specified a different type of process for each of the three sub-systems. The armature manufacturing line was specified as an asynchronous loop to gain the advantages of Visteon defined independent machines. For the assembly line, the system integrator was responsible, with Visteon design approval, for both the machinery and system integration to leverage their small part assembly expertise. Since it has a high level of expertise in such machines, Visteon specified the test system design in detail.

This example shows several important factors in purchasing manufacturing lines. When the system integrator is free to propose a design, as in the assembly system, the result will be based on the integrator's particular technology. For the test line, the Visteon engineers specified the detailed machine design to implement their expertise in performance testing. For the armature process, the Visteon engineers specified individual machines for the system integrator to put together. It should be noted the assembly and test lines were successfully installed, while the armature line had throughput issues during the initial production launch. In the successful lines, one party had control over the entire design process, while in the armature line design responsibility changed after the machines were selected.

When the Visteon manufacturing engineer wants to outsource a new or innovative process, the capabilities of the system integrator may stretched. This can be viewed in two dimensions, in scope and capability. In operating large systems, manufacturing plants see many types of challenges and programming problems which the integrators may not recognize as important. Thus, they may be designing beyond their scope, not having the required knowledge in plant logistics, union relations, and maintenance procedures. Also, when implementing new practices, like lean cells, the integrators may have limited expertise in that type of line or operation. This situation requires a higher level of knowledge transfer from the Visteon engineer to the supplier.

### 2.3.2. The Development Process from the System Integrator's Perspective

System integrators view the development process differently than Visteon engineers. A group of system integrators were interviewed to develop an understanding of their line design process. In general, the system integrators focus on meeting capacity requirements from the time a Request for Quotation (RFQ) is received to line delivery. Reliability and quality specifications are considered as part of the feasibility of proposed designs. The integrator's process designers also noted the large number of specifications as an inhibitor in the design process. In addition to the system specification from the engineer, Ford corporate, divisional and plant specifications are included to ensure the design conforms to Visteon's safety, maintenance and operating standards. To a machine builder, changing a standard design machine to meet these specifications adds considerable cost.

System integrators also add cost into quotations to cover for risk. Risk may be the result of a new concept like cellular manufacturing or open specifications as in unlimited flexibility. When responding to a request for quotation, the system integrator is under severe time constraints that require conservative estimates. One solution to this challenge is for the integrator to assume that since previous work has been acceptable, they should plan on that level of compliance and budget to cover unknown but expected changes to meet the specification.

The Visteon engineer's relationship with the system integrator must recognize these challenges. The engineer is purchasing a new line while brokering the relationship between the purchasing plant and the system integrator. From the integrator's perspective, Visteon specifies items that add some cost and time to the development process. However, the plant, operators, and supply chain have requirements that may not be obvious to the system integrator. To the plant, mechanical and controls specifications represent the facility's accumulated knowledge regarding equipment design. For example, plants reduce spare parts inventory by only using specific standard parts. Equipment specifications are designed to minimize total life cycle costs, which includes purchase, maintenance, operation, and inventory costs. Thus, plants may only allow one or two manufacturer's air cylinders on equipment, and the vendor may have to change a standard design.

## 2.4. The Current Use of Analysis and Improvement Tools

This section overviews the project and analysis tools used by the Visteon Operations Engineering group. A summary and analysis of the projects the Operations Engineering group has recently completed is given. The section concludes with a review of the tools currently used for process analysis.

### 2.4.1. Current Uses of Simulation Tools

Within Visteon, discrete event simulation is used for process design verification. When a Visteon plant is performing the integration, they typically simulate the new process. For designs sourced to a system integrator, the supplier is required to verify the capacity and operation of the process with a simulation study. System integrators also verify material handling and programming strategies with the simulations, but only for the sub-system that they are designing.

One problem with this approach is that the entire system may not be simulated, only the different sub-systems. The implicit assumption is if all the sub-systems work to specification, the plant will not have any problems running the complete system. Since after launch the plant controls the new line, the manufacturing engineers may not be aware of sub-system integration issues. These issues are also less obvious than sub-system capacity issues and can be worked around by having the plant hold inventory or work different shift patterns.

A primary user of simulation within Visteon is the Operations Engineering group. However, the focus of their projects has been on improvements to existing systems. Operations Engineering projects that have involved design have had limited success, since the new process design often changes before a simulation model can be completed.

### 2.4.2. The Current Role of Visteon Operations Engineering

The Operations Engineering section performs projects for all of Visteon, though most of its work has been done in the Electronics, Plastics, and Climate Control plants. A survey of current and recently completed projects is given in Table 3. The projects are categorized in two areas: the types of analysis required and whether the project involved a greenfield or brownfield site. The second distinction is important since existing plants in the United States are generally older, United Auto Workers organized, and have processes already in place. With the globalization of the automotive components industry, Visteon divisions are rapidly expanding into new markets, including Latin America, Asia, and Eastern Europe. These new operating plants are often greenfield sites where Visteon has a joint venture partner. Projects for the new facilities offer an opportunity to do a clean sheet analysis.

**Table 3: Operations Engineering Project Summary**

| Project | Capacity | Logistics / Inventory | Layout | Material Flow | Brownfield | Greenfield |
|---|---|---|---|---|---|---|
| Projects | 12 | 12 | 7 | 4 | 14 | 7 |
| Percentage | 57% | 57% | 33% | 19% | 67% | 33% |

Since the typical Operations Engineering project includes more than one type of analysis, the percentages sum to greater than 100%. The table is an analysis of 21 recent projects undertaken by the section in 1996 and 1997.

A majority of the projects the Operations Engineering group completes involve discrete event simulation, typically done using the *Witness* program. A diagram of the manufacturing development process was shown in Figure 1 (section 2.1.1). The initial uses of simulation at Ford were in the area of process improvement, after the process had been designed and placed in operation. Over time, the use of simulation has moved upstream in the design process to where it is used to validate proposed designs before they are implemented. At this point in the process there is greater leverage and ability to change a line design for capacity or efficiency improvements.

The Operations Engineering section is looking to the design methodology to move the use of Operations Research analysis into the process design stage. One of the section's primary responsibilities is to provide analysis tools and training to manufacturing engineers, which makes the group a resource for Visteon. The next section reviews some of the Operations Engineering group's analysis tools used and the issues regarding their acceptance by manufacturing engineers.

### 2.4.3. Current Analysis Tools

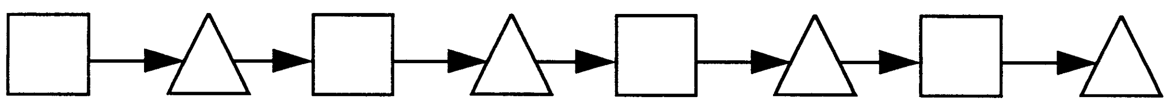
This section reviews the most frequently used analysis tools of the Visteon Operations Engineering group. The tools and issues surrounding their use are discussed.

***Discrete Event Simulation - Witness.*** The primary tool used for process analysis is the Lanner Group's *Witness* discrete event simulation program. Since *Witness* is its standard simulation package, Ford offers training courses at the Fairlane Training and Development Center, user support through the Ford Simulation Users Group, and an on-site help desk staffed by a Lanner employee. *Witness* is difficult to learn, as an initial class takes 32-40 hours and does not provide the required expertise and background in collecting data and choosing the type of model to build. *Witness* is used both for process improvement and to verify process proposals.

For any general simulation tool, the inputs and outputs of a model depend on the questions the analyst is trying to answer. Since the program can model almost any continuous or discrete process, the analyst must determine the appropriate level of detail, the data required, and the scenarios to test. Such analysis requires experience to determine where resources and effort are appropriately placed, making the program difficult for most manufacturing engineers without the aid of an outside programmer.

***Custom Programs – AccuCAM:*** *AccuCAM* is an analysis tool developed by the Visteon Operations Engineering section. Written in Visual Basic, it is an *Excel* macro program that provides a serial line capacity analysis. The program provides information on actual capacity, maximum capacity with infinite buffers, and capacity with no buffers between stations. *AccuCAM* assumes a transfer line with a configuration given by Figure 3:

**Figure 3: Assumed Process Flow for *AccuCAM***



Where operations are denoted by squares, and buffers are denoted by triangles. Many of the existing processes within Visteon are transfer lines, albeit on a smaller scale than in a vehicle assembly plant.

*AccuCAM* is distributed through the Ford intranet, as a download from the Operations Engineering web site. The users of *AccuCAM* are the Operations Engineering analysts and a small number of manufacturing engineers. Without a push to engineering, few groups will discover a need for such a program unless they begin to question the traditional relationship with system integrators, which places the analysis and throughput responsibility on the suppliers.

***Material Flow Analysis - Factory Flow:*** To analyze material flow through a plant, the Operations Engineering group utilizes *Factory Flow,* an *AutoCad* add in. Given an *AutoCad* layout, the analyst can study the traffic and flow patterns through a plant to relieve congestion and minimize travel distance.

The program requires the plant layouts and flows through the plant for each product being studied. Given the costs of transporting the material, the program will calculate the costs of material handling throughout the system. The most used output is visual indications of the flows, with line thickness indicating amount of traffic. This analysis provides an intuitive, easily interpreted indication of plant traffic and improvement opportunities.

Typically, this tool is used in new joint venture plants to verify and improve the proposed layouts. Existing plants have limited opportunity to benefit *Factory Flow,* due to the mix of old and new lines. Since large scale rearrangements of existing processes are time consuming and expensive, most plants are unable to radically change the layout for each new process. Given this limited opportunity, and the high cost of the program, few engineering departments or plants utilize *Factory Flow.*

## 2.5. Quality Function Deployment and the Analytical Hierarchy Process

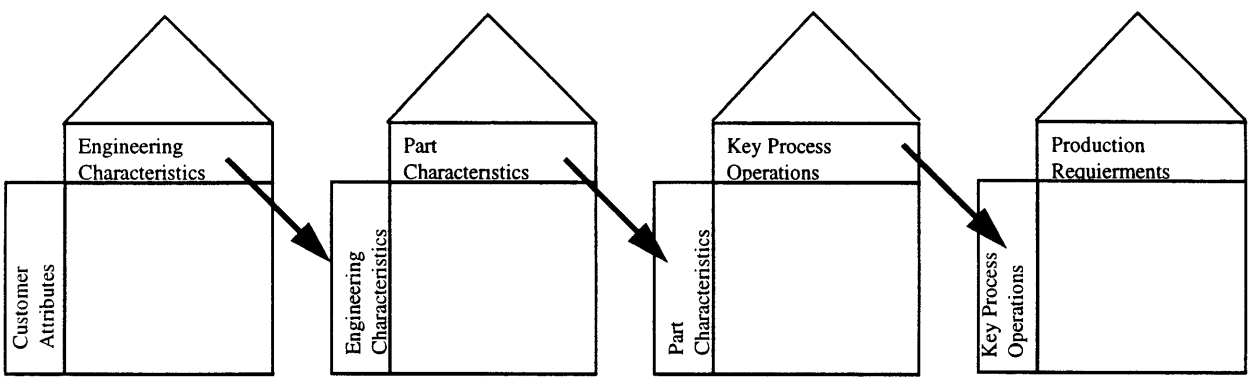
Two tools are reviewed here for use in the proposed process design methodology. Quality Function Deployment (QFD) is an objectives driven approach to design, used to map customer needs into product designs. The Analytical Hierarchy Process (AHP) is a decision making tool, permitting a complex problem to be broken down into smaller, more manageable decisions. The use of these tools also facilitates communication between the different groups involved in the development of new manufacturing processes.

### 2.5.1. Quality Function Deployment

Quality Function Deployment is traditionally used in product development as a means of translating the "Voice of the Customer" into engineering characteristics and design attributes. Beginning with customer needs in the language in which they are stated, the QFD process translates these needs through engineering and process characteristics, down to manufacturing characteristics. A visual process, QFD allows communication and understanding of how the product design meets the needs of the customers, as well as how different characteristics interact. One of the most important aspects of QFD in product and process development is it requires asking the customers what they want, and not trying to interpret or presume these needs.

Traditional QFD uses four houses to link the customer's voice to production requirements (Hauser and Clausing, 1988). As shown in Figure 4, the process begins with the recording of customer needs, usually categorized in hierarchical format, defining primary, secondary, and tertiary levels of needs. The customer attributes are then linked with engineering characteristics, which are product details that can be modified to affect the associated customer attribute. An important part of the process is reviewing each engineering characteristic on how it affects each customer attribute, and the interaction with other engineering characteristics. In the second house, the engineering characteristics from house one move to the left side of house two. The top row is now part characteristics. The third house translates part characteristics into key process operations for the manufacturing process. The fourth and final house takes key process operations and translates them into production requirements.

**Figure 4: QFD Houses**




Adapted from Hauser and Clausing, 1988

Griffin and Hauser (1993) list four roles of QFD. The first is its stated use of developing specified target values for each of the design attributes. Another is using QFD to guide the design process and make decisions. A third is to facilitate communication between different corporate departments, and finally QFD is used to provide specifications for design attributes. Ulrich and Eppinger (1993) use a similar *needs-metrics* matrix as part of the specification development stage of their product development process.

The use of the first two houses of QFD is well established in the product engineering community. Classroom training in the QFD process is available at the Ford training center, and software to facilitate the process is also available. In practice, QFD is rarely used to drive the entire design process, but it ensures customer needs are discovered and met in a product design.

It is also useful in integrating the product and manufacturing design processes when used to completion. The QFD process is also extremely useful in facilitating communication between different groups within and outside of Visteon.

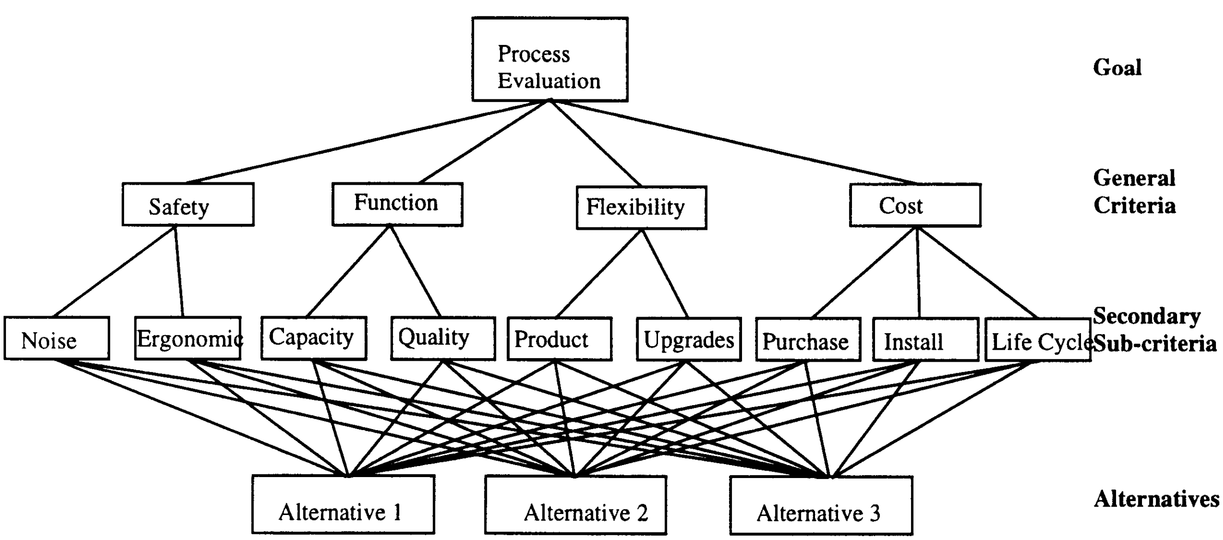
### 2.5.2. The Analytical Hierarchy Process

The analytical hierarchy process (AHP) is a means of breaking a complex decision problem down into smaller, more manageable sub-problems, which allow pairwise comparison of alternatives. Developed by Saaty (1980), AHP is a logical framework that decomposes a problem into a hierarchical structure, and uses a linear weighting scheme to evaluate overall alternatives. There are three principles in AHP: decomposition, comparative judgment, and synthesis of priorities. By breaking down a problem, evaluating the alternatives relative to one another, and then synthesizing the results, AHP allows a logical decision to be made from a group of alternatives.

AHP assumes a set of alternatives has been determined, and each is a capable solution. The process is of value in choosing between complex alternatives from which no best answer is clear. It allows the team to discuss and evaluate various aspects of a decision in small segments, and to evaluate the alternatives on a relative basis. The procedure then synthesizes the results into a final general result, rating each segment by its relative weight.

The decomposition of a problem is structured as a hierarchy, as shown in Figure 5:

**Figure 5: AHP Example Hierarchy**



The hierarchy begins at the top level with the overall goal of the analysis. General criteria, the second level of the hierarchy are then determined, as are the sub-criteria for each of the general criteria. The sub-criteria can be taken through as many levels as are required to break the evaluation down to a level where the different alternatives can be evaluated.

After the hierarchy has been determined, the criteria must be evaluated relative to each other. The scale proposed by Saaty (1980) is commonly used (Figure 6).

**Figure 6: AHP Ratings Scale**

| Verbal Scale | Numerical Scale |
|---|---|
| **Equally important, likely or preferred** | 1 |
| **Moderately more important, likely or preferred** | 3 |
| **Strongly more important, likely or preferred** | 5 |
| **Very strongly more important, likely or preferred** | 7 |
| **Extremely more important, likely or preferred** | 9 |
| **Intermediate values to reflect compromise** | 2, 4, 6, 8 |
| **Less important** | Reciprocal of above |

The next step for the team is to rate each of the general criteria using the above scale. Selecting a base criterion and rating the other general criteria relative to the base does this. If a criterion is determined to be less important than the base, the appropriate reciprocal is used. After each of the criteria is rated, the same process is used for each of the sub-criteria levels. For each general criteria and sub-criteria, the relative weightings are found by taking the individual ratings divided by the geometric mean of the total. From the hierarchy, it can be seen that the sums of the sub-criteria weightings are the relative importance scaled by the criteria weighting.

Using the same scale, each of the alternatives is then rated for the lowest level sub-criteria. The sub-criteria and general criteria weights then multiply these relative ratings. All of the weights for each alternative are summed to get the general, total score for each alternative, with the largest score being the best choice.

The entire decision need not be done from one hierarchy. If desired, benefits, costs, and risks can be evaluated with different hierarchies (Saaty, 1994). The best solution can then be found by synthesizing the results for each hierarchy, and taking the appropriate benefit/cost or benefit/risk ratio. This permits a separate analysis of each segment of the problem.

There are two significant benefits from the AHP approach to making a decision. First, the process is easily automated in a spreadsheet format. This permits easy programming and modification, as well as promoting easy distribution throughout Visteon. Secondly, AHP, like QFD, promotes team communication. When determining the hierarchy and weights, the team discusses different aspects of the project in a defined manner, taking each concern in turn. This formal approach leads to more open and straightforward communication. The AHP process works best when there is one recognized facilitator who can keep the team on track and arbitrate any disagreement to keep the process moving.

## 2.6. Benefits of a Process Design Methodology

### 2.6.1. Guidance for Manufacturing Engineers

One of the major benefits from a process design methodology is providing guidance for manufacturing engineers. At a minimum, a methodology provides a checklist of what must be accomplished designing a new manufacturing line. Lacking a methodology, the engineer defines what must be done, creating the opportunity to miss requirements or delay the program. A process design methodology also lists tools for use in the design process, which aids the engineer in understanding how to achieve the goals of the project.

As Rao and Gu (1995) note, a manufacturing engineer faces an enormous amount of data regarding objectives and constraints. A design methodology helps put this information into perspective, focusing the task of process development. This is important in a large organization where different departments are involved in process design.

Ulrich and Eppinger (1993) give three reasons for the use of structured methodologies in product design, and they apply to process design as well. First, methodologies permit everyone on the team to understand and support decisions. Second, a methodology acts as a checklist on the design process. Finally, a methodology makes the process self-documenting, permitting learning across projects.

### 2.6.2. Systems Thinking in Process Design

Another benefit of a design methodology is it forces systems thinking onto the manufacturing engineer. Much like QFD, a design methodology supports both high level strategic thinking and the detailed work required of the engineer. A design methodology requires focused thinking on plant and supply chain performance, as well as on individual machines. This is a different focus for many manufacturing engineers, who are trained in detailed machine design.

A design methodology also requires the process be total cost driven and not Labor and Overhead focused. Before the implementation of the Ford Production System, the driver of plant performance was a traditional labor based accounting system that emphasized labor costs in performance evaluation. FPS, in contrast, emphasizes minimizing total cost, which includes capital, labor, and other manufacturing expenses.

By focusing on needs, objectives, and constraints, a design methodology would also overcome any parochialism in the development process. New concepts are required in the changing competitive environment Visteon faces, which forces change in the engineering and management disciplines. As noted by Grossman (1997):

> Many times, potentially wonderful ideas get discarded because technical people are trained to look for what's wrong with new ideas instead of what's useful.

Finally, a methodology leaves the design expertise with the manufacturing engineer, whose knowledge and experience are well above what any general method could provide. Rao and Gu (1995) summarize this point with:

> A proposed design methodology can only outline and specify the needs of modeling and structuring the manufacturing system. It is up to the modeler or designer to come up with approaches to implement the objectives and logical reasoning outlined in the methodology.

# 3. Proposed Manufacturing Line Development Methodology

This chapter proposes a design methodology for manufacturing processes. Several product and process design methodologies are presented, and then an overview of the proposed methodology is given. Each step of the proposed methodology is described, defining the inputs and outputs for each stage.

## 3.1. Product and Process Design Methodologies

Successful product design methodologies have focused on determining the needs of the customer, and then directing design efforts on meeting those needs. In contrast, most process design methodologies begin by assuming the type of line required, and then build a framework around creating a specific type of process. Several methodologies are reviewed here for background.

### 3.1.1. Product Design Methodologies

Product design methodologies are a relatively well documented subject, and this research drew ideas from two different sources. The Ulrich and Eppinger (1993) product design methodology determines the needs of the customer and designs a product based on those needs. The generic product development process given in their text provided the starting point for this methodology.

Shiba, Graham and Walden (1993), also emphasizes determining the voice of the customer by interviews and language analysis. This research used their process to understand the environment of a Visteon manufacturing engineer, the system integrator, and the plants within the company. These results provide insight into the tools an engineer needs for process design, as contrasted with those used by the Operations Engineering section.

### 3.1.2. Process Design Methodologies

Rao and Gu (1995) propose a design methodology for manufacturing systems that they then use with a genetic algorithm approach. Their methodology includes five stages, not unlike those typically proposed for product design:

*System Conceptualization:* The designer identifies the needs, goals, and objectives for the proposed system. At this stage constraints are also identified.

*System Structure:* This is the development of system specifications from the known needs and constraints.

*System Implementation:* At this stage the engineer develops detailed specifications of the process, including hardware, communication, control, and personnel. Testing also occurs at this stage.

*System Operation:* The actual operation of the system, this stage also includes verification of the system performance.

*System Reconfiguration:* This stage is intended to identify the changes that are required for the system to accommodate differences from the forecast needs and constraints.

In *Making Manufacturing Cells Work,* Nyman (1992) proposes a set of steps for implementing cells in an existing plant. In this approach, the team works on macro facility planning, conceptual cell development, concept evaluation, material handling and control systems, and finally, detailed design. Nyman's application also provides useful spreadsheet analyses to aid the engineer in designing a system of manufacturing cells for the plant.

Most proposed process design methodologies assume a manufacturing process technology. An example for flexible manufacturing systems is Tempelmeir and Heinrich's *Flexible Manufacturing System Decision Support for Design and Operation* (1993), which details the process of implementing FMS systems and reviews performance analysis methods. The new methodology this thesis proposes attempts to determine the technology based on the project needs, and then lead the manufacturing engineer to the type of line required.

## 3.2. Proposed Methodology Overview

### 3.2.1. Background

This new process design methodology is a top-down, objectives based approach to manufacturing line design. The methodology considers the needs and constraints imposed by the product customer, plant management, operators, supply chain, and product design. To accomplish this, the manufacturing engineers must obtain input from across organizational boundaries and functions.

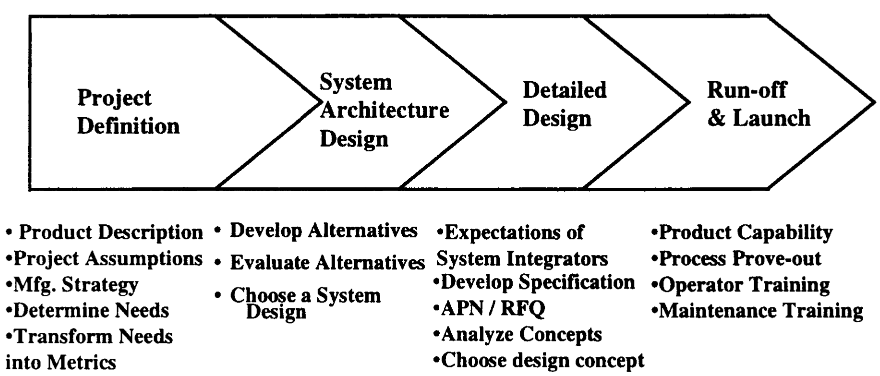
The methodology is structured to use a set of tools for facilitation and concept analysis. Use of a structured method facilitates communication between cross-functional team members, as well as ensuring all the process steps are completed. Analysis tools provide objective criteria for the team to compare proposed design concepts, leading to better decisions earlier in the design process.

Process design includes establishing a cross-functional team with members from various business functions. A typical team includes personnel from manufacturing and product engineering, plant management, operators and skilled trades, finance, and controls engineering. The process is facilitated by the manufacturing engineer, with the involvement of other team members as required in each step of the methodology.

The methodology requires designing a system to satisfy each of the stakeholders affected by the process. Customers, the purchaser of the manufactured product, demand quality and delivery reliability. Operators require useable interfaces with the equipment and information systems, and must accept the new work environment. Each plant has a different management structure and philosophy that must interface with the process, including information flows and process control systems. The purchased part supply chain can place constraints on the scheduling and inventory control of the production system, while current and future product characteristics may limit the process design.

The overall flow of the methodology, with the major steps, is given in Figure 7.

**Figure 7: Manufacturing Design Methodology Flowchart**



As indicated in the flowchart, the process begins by defining the project, including the product and business assumptions. In project definition, the division's manufacturing strategy must be identified to ensure the new process aligns with business objectives. This typically includes identifying the types of processes used, the current and future product mix, and available labor and other resources available. Finally, the engineer transforms needs into design metrics using the QFD process.

The system architecture design stage considers material flow, inventory control and other system performance issues. The designer creates and evaluates a set of design alternatives based on the system level metrics from the project definition stage. In the final step, the engineer selects a system level design for the new process.

The detailed design stage includes specification development, vendor evaluation, request for quotation, and final concept selection. The engineer first determines expectations for the system integrators, and selects appropriate vendors to quote the new process. To ensure a complete specification, the engineer develops requirements based on the transformed needs from the project definition stage. After the quotation process, concept analysis leads to the choice of a vendor.

The build, run-off and launch phase includes the evaluation and installation of a new line. This includes developing acceptance criteria and evaluating product capability. Working with the plant, the engineer must also develop operator and maintenance training. This is the final phase before regular operation.

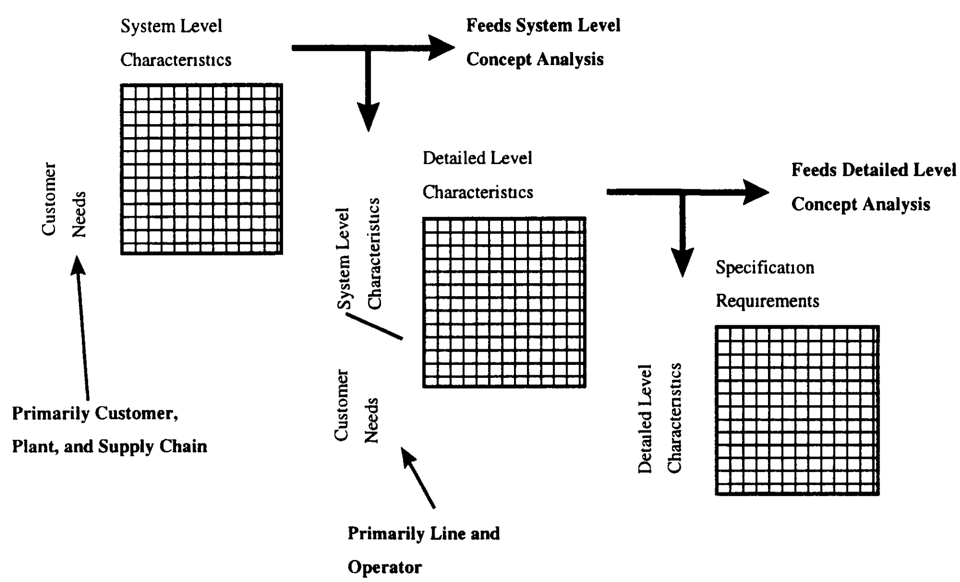
### 3.2.2. The Use of Quality Function Deployment

The new methodology utilizes Quality Function Deployment (QFD) to map needs into the system level and detailed designs of a new process. As shown in Figure 8, the process takes the customer's needs on the side of the first house, and translates them into system architecture level characteristics. The first house consists of primarily customer, plant, and supply chain requirements, since they are concerned with overall system performance. The engineer evaluates system level design alternatives based on the system level characteristics, as well as transfers these characteristics to the second, detailed design QFD house.

The second QFD house takes the system architecture characteristics, and relevant detailed needs, and translates these into detailed level characteristics. The second level needs are primarily product design, process, and operator needs. The use of QFD in this way can also aid in the concurrent engineering process. As product and process design requirements are developed, they can be evaluated for their effect on the other process. For example, product design requirements can be evaluated in terms of the process requirements, identifying areas to consider for revision in the product design.

The third and final house takes the detailed level characteristics, and transforms them into specification requirements for the system integrator. This use of the QFD process ensures stakeholder needs are translated into the specification for the end system.

**Figure 8: QFD Method for Process Design**




## 3.3. Project Definition

The first design methodology stage is project definition. Project definition includes establishing the project scope and mission and identifying the stakeholder's needs.

### 3.3.1. Establishment of Scope and Mission

A brief but important stage of process development is establishing project scope. The engineer identifies project assumptions, manufacturing strategy, and the product description with input from the business planning and product engineering functions. It is important for the engineer to specify the type of process development required. Ulrich and Eppinger (1993) summarize different types of product development as market pull, technology push, platform products, process intensive, and customized. Similarly, manufacturing processes can be classified into different development types.

For Visteon, most new lines can be considered platform development processes, where the new line manufactures a product similar to its predecessor. The development of cellular lines represents a market pull, where Visteon is designing for changing market requirements. New process technology often follows a technology push product, since existing processes cannot manufacture the new product. In the end, the engineer modifies the development process based on the type of line, with less design effort required for platform development. The output of this stage of the methodology is a listing of assumptions, strategies, and development requirements that guide and constrain the line design.

### 3.3.2. Identification of Stakeholder Needs

The manufacturing engineer must identify the needs and limitations of the various stakeholders in the new manufacturing process. For most process designs, members of various affected business functions can participate in the needs identification process.

The team begins by entering needs on the left side of the first QFD house. The FPS principles are included, as they define the operation for all Ford manufacturing facilities. The team segments needs by stakeholder, which provides structure to the brainstorming session.

In addition to needs, the team lists constraints the design must consider. While the recording of constraints is important, each should be questioned and understood by the team. At this stage of the process, Shiba's (1993) 'I Already Know It' learning block often occurs. This learning block arises when someone fails to understand and apply existing information to the current problem, because they think they already know the answer.

After the needs have been listed, the group goes through each of them and develops metrics for the design. This requires expertise in each aspect of the process to ensure the development of a good design. Again, there is an advantage over product design in the limited number of people involved. Rather than having to interpret customer statements, the department involved can directly translate the requirement and explain to the rest of the group.

Ulrich and Eppinger (1993) list caveats for product design metrics, which apply here also:

- Metrics should be dependent, not independent variables
- Metrics should be practical

- Some needs cannot easily be translated into quantifiable metrics

The team lists target values for each metric in the QFD house. The team also considers whether each metric affects a system architecture or detailed machine design parameter. Listing an S for the system architecture level or D for the detailed level beside each metric permits separation in the later design stages. While some team members find these steps obvious, the common understanding developed throughout the group is important.

Benchmarking information is taken into account at this stage. In process design, benchmarking may include visiting unrelated product manufacturing sites to understand the implementation of different concepts like operator managed work teams, lean manufacturing cells, or specific order and delivery systems.

As a final stage of metric determination, a check is made to ensure requirements have not been missed. These may include process, monitoring or control system, material handling, software, material flow, layout, maintenance, management, safety, implementation, and cost requirements.

## 3.4. System Architecture Design and Testing

After the design metrics have been determined, the engineer begins the overall system architecture design. System design determines how material will flow through the plant and the process technology involved. A set of alternatives is created, considering layout and other restrictions, with a final selection completing this phase.

### 3.4.1. System Architecture Considerations

***Determination of Process Requirements:*** The engineer first must determine the operations or processes that are required to produce the product. Rao and Gu (1995) describe how system operational requirements govern the design of an entire manufacturing system. This includes recognizing that all forecasts in customer demand will be uncertain, and the operational requirements must be determined to accommodate such variability.

The first step is listing the physical processes required to produce the products. This includes processing steps, desired lot sizes, materials, part sizes, and gages. These are laid out in a process flow diagram, showing the relationships of different processes, and any precedence relationships.

***High level system flow:*** The next stage is determining where in the plant processes will be located and how material will flow. In a brownfield plant this stage involves optimizing flow constrained by available floorspace and working around existing lines.

Developing material flow through the plant is an area many manufacturers fail to consider. By focusing on individual sub-systems, the entire system is sub-optimized. When a plant implements the sub-systems as one manufacturing process, the resulting line is not optimized for performance. As noted by Suzaki (1987) in his introduction to flow, such systems accumulate inventory and other problems since total production has not been optimized.

At this stage, the engineer details the process and operating parameters that will affect operations. These include shift patterns, Work In Process (WIP) and buffer requirements, and process and service time for each process. These parameters are used in the analysis against the system architecture metrics. For example, if a process has an 8-hour cure time, buffering must be used to avoid starvation of the next process if unexpected changeovers are required.

***Process choice:*** After the process flow is understood, the engineer must determine what type of system will be used for each process. If the operation does not determine the process, e.g. injection molding, the engineer must determine the type of line to be used. These include asynchronous loops, manufacturing cells, and transfer lines. The type of line chosen will be heavily dependent on the manufacturing strategy for the plant or product line. For example, manual transfer lines are often used in initial applications of a new product.

### 3.4.2. Development of System Design Alternatives

System alternative development requires integrating process requirements, system flow, process type, and other considerations into a set of feasible solutions for evaluation. To take a systems approach to the problem, various brainstorming techniques are available to facilitate the process. The objective is exploring non-obvious solutions to improve total system performance (Hopp and Spearman, 1996).

As a starting point in developing design alternatives, the first QFD house is used to facilitate the process. The listed requirements along the top of the house outline the characteristics the process must have, and focus the team on means-end thinking.

In developing concept designs, additional inputs need to be considered. Within Visteon plants the accounting and control structures are developed around financial departments, usually based on a segment of the process. Selection of the departments has a direct impact on system performance evaluation, future improvement, and product design characteristics. A financial department produces a component or sub-component to a product print, which may be built by Visteon or purchased from an outside vendor. Such a component also allows for competitive benchmarking through the purchasing function. The team must make both an initial make-buy decision, as well as determine assumptions about how future products will be made or purchased.

Alternative generation should include benchmarking, both externally and internally. Solutions to problems and new concepts are often discovered through benchmarking other similar processes and products.

In generating design concepts, the manufacturing engineer doesn't have to create a large number of options. Often the physical processes dictate what type of process is used, for example injection molding or painting. The more difficult decisions will be determining what type of machining, assembly, or test system to implement. These are operational decisions, and not processing requirements, as the decision affects WIP levels, management, operator responsibility and maintenance requirements.

Individual and group brainstorming is used to generate a set of system level concepts. The concepts should define the general plant layout, the types of processes required, and how the sub-systems are expected to interact. Plant operations management and information flows should be considered, as well as operating patterns and material flows. The final list should be agreed upon by the team and documented as part of the design process. It is important for feasibility to be assessed to avoid repetition and waste of analysis resources.

For example, a standard electronic component line may require a surface mount device (SMD) circuit board be assembled to a housing before final testing. Since the process requirements are given by the product design, the design team must first consider the system flow. The team decides if the SMD line is to be part of a functional department, or if this is to be a 'plant within a plant' system with SMD, assembly, and test located in the same area. This decision leads to the required buffers and information flows within the system.

The second step for the SMD line is choosing process types. For example, the assembly system could be an automated asynchronous loop, a manufacturing cell, or a manual line with a conveyor. The type of process chosen will determine characteristics including operator requirements, changeover times, and the cost of product line flexibility.

### 3.4.3. Alternative Evaluation and Selection

After a set of viable alternatives is created, they must be evaluated against the pre-determined metrics and specifications from the QFD. Nyman (1992) suggests alternative evaluation implies:

- A clearly stated strategic and technical objective
- A series of viable alternatives
- A clear definition of each alternative
- A list of criteria or factors to be met
- An accepted methodology to evaluate alternatives

***Determining alternative viability:*** The engineer must analyze the alternatives to determine if they meet the established criteria. At this stage of the process, the engineer does not require the detail provided by a full simulation, but rather validation of a design concept. The analytical tools described in Chapter 5 are intended to meet this requirement.

The analysis criteria are derived from the QFD process. The system level results are used to evaluate each proposal to determine if it is a viable solution. The engineer should utilize a procedure that compares alternatives to the derived metrics, utilizes available analysis tools, and in the end, verifies the design concepts.

An important step in evaluation is providing design feedback for iteration. A good analysis tool not only answers the questions put to it, but also provides the engineer with insight on how to improve the design. It should be noted many system requirements are qualitative, and cannot be measured. The QFD process will maintain the requirements, and the AHP process allows for their evaluation.

### 3.4.4. Choose a Concept

After a set of viable system architecture alternatives is created, the engineer must decide which concept to implement. If the decision is complicated or not obvious, the AHP method is used to determine the best choice.

In choosing a system level design, technological and implementation risk must also be considered. In an existing plant, the management-union relations, communication systems, and scheduling systems are all factors in the success of a line. Making changes to any fundamental plant system involves risk that must be understood. For example, if a plant is organized around process centered departments, implementing a pull system from cross-loaded injection molding equipment implies buffer inventory and high process time through molding. To implement a synchronized pull system, new control and management procedures must be implemented. Gaining acceptance for such a system requires a high level of communication and training with the operators and plant floor management.

The methodology for using AHP is as follows:

1. Determine the overall goal
2. Determine the hierarchies required (benefit, cost, or risk)
3. List the general criteria
4. List the secondary sub-criteria for each general criterion
5. Determine the relative weightings for each criteria
6. Determine the relative weightings for each sub-criteria
7. Rate each alternative for each sub-criteria
8. Synthesize the results
9. Determine the final choice

The overall goal is the objective of the system level design. This may include both metric and strategic driven standards. Determining the hierarchies involves deciding if there is a question of the benefits outweighing the costs, which implies two hierarchies (Saaty, 1994). The same process is used if there is a concern with risk. In practice, most decisions can be made with one hierarchy if the process facilitator can maintain the inverse ratings relationship with higher costs being less desirable.

## 3.5. Detailed Level Design and Testing

After the system structure has been determined, the detailed design of the manufacturing process begins. The first step is determining the design metrics from the QFD process. Next is the determination of the expectations of machine builders and system integrators involved in the process. The specification becomes the key document in the relationship with the suppliers, and drives the request for quotation (RFQ) process. After proposals have been submitted, the evaluation and selection process takes place. The result of this phase is a selected vendor and final vendor design concept, which includes detailed machine and tooling designs.

### 3.5.1. Determine Detailed Design Requirements

The first step in detailed design is determining the requirements from the QFD process. This involves taking the applicable metrics from this methodology's original QFD house and the system level characteristics and placing them on the left side of the second house. Like in the system design, the top of the house becomes the means of achieving each requirement. Again the standard QFD process is followed to fill out the main room of the house.

The methodology's second QFD house has two purposes. The results are used to feed the specification for the suppliers to prepare concepts and to drive any design that must be done by the engineer. Other design requirements will come from manufacturing standards, plant specifications, and any applicable division equipment specifications.

In determining the means of implementing requirements, attention should be paid to qualitative requirements as they are implemented in the design. Operator controls and information systems that are often specified as 'easy to use' or 'meet standard' are developed at this point. The requirements of the operations should be understood when defining the means of implementation. If the requirement is for a start button the operator can actuate when walking to the next station, the callout is different than for a fast set of palm buttons for a stationary operator. These decisions have safety implications and require the design adhere to accepted safety and ergonomic standards.

Returning to the SMD assembly line example, if an automated asynchronous loop has been chosen, the team may specify operator interfaces, information system requirements, machine safety equipment, and quick change tooling heads as part of the process. The objective is to develop specific line requirements that meet the type of process chosen and the characteristics of the plant that will operate the line.

### 3.5.2. Determine Expectations of Suppliers

Since Visteon outsources most equipment manufacturing, the choice of suppliers is an important process in line development. Suppliers range from basic equipment vendors for standard tools such as lathes and mills to large integrators who design or purchase machines to integrate into unique processes. To ensure a successful project the engineer must understand both the expectations of the suppliers and their abilities.

***Scope of the project:*** It is important the engineer understand how the supplier will be affected by the project scope. The issues to be addressed include floorspace, project management, mechanical design, electrical design, and material handling requirements. These questions must be answered before specification preparation and vendor selection.

If the integration is to be done by the supplier, expertise is required in control systems design, computer integrated manufacturing (CIM), material handling systems, and machine design. These aspects of the integration require the expertise to design and develop complete systems that will not only function independently, but also interface with the Visteon plant systems.

The choice of machine suppliers involves a trade-off for the Visteon engineer. The system integrator usually has developed relationships with machine suppliers, and as a result the integrator is familiar with their capabilities and design requirements. Visteon may wish to use different machine builders than the system integrator, which may create issues with equipment integration. While the integrator may be able to implement at lower cost with their machine suppliers, the costs of maintenance and training for the buying plant must be included in the cost equation. The final decision should be based on the total life cycle costs of the equipment, which take into account the purchase, installation, and operational costs.

Financial stability is also a concern in choosing a system integrator. The cost of large assembly systems often exceeds $10 million, which the system integrator must be able to absorb until delivery. Should integration problems delay the line acceptance by Visteon, the system integrators may have machine builders demanding payment, resulting in a cash flow problem.

If the integration is to be completed by the Visteon plant, the expectations of the machine builders are much smaller. The primary question is whether the equipment is to be off-the-shelf standard machines or unique designs for Visteon. If standard designs are acceptable, the engineering and production costs are much lower, sometimes 5-35% less. If modified machines are required, the supplier must have the capability to not only design the new equipment, but also to understand and integrate the Ford specifications to be used. This may include the use of unfamiliar controllers, pneumatics, and hydraulic systems that may not be interchangeable with existing components.

***Technical capabilities:*** The engineer evaluates three technical factors in the vendor evaluation process. The first is identifying system integrators with expertise in the type of system chosen in the architecture design stage. If experienced suppliers cannot be identified, the engineer faces a more difficult development process. A high level of coaching and supervision will be required of the Visteon engineer during the design process, which must be reflected in the specification.

When a new technology is required, the engineer must understand who will be responsible for the technical development and implementation risk. If the integrator is to develop the new concept, the Visteon engineer must verify their technical capability. In cases where Visteon or Ford is developing the technology, the integrator must be willing and able to work with the responsible development group. Some system integrators are reluctant to enter development contracts where they are limited to someone else's technology or machine builder.

Finally, the level of creativity the system integrator can provide is assessed. In general, system integrators prefer an open specification to develop a process that best combines their expertise and the customer's requirements. The Visteon engineer must consider the level of detail in specification development, as increasing detail limits integrator creativity. Detailed specifications ensure the proposals meet the engineer's intent, and provide clear expectations on the equipment purchasing process. Two detrimental results from overly detailed specifications are delays from specification revision, due to issues brought up by the system integrators, and a deterioration of the integrator-engineer relationship.

### 3.5.3. Specification Development

To ensure capable equipment, a well prepared, appropriately detailed specification is required to begin the purchasing process. This requires a well-developed document that includes the required performance of the process, the type of line, the communication and control systems, and how the line will integrate into the plant environment. The specification also becomes the baseline all future line revisions and modifications are compared to after a vendor has been chosen, so it must accurately reflect the desires and expectations of the Visteon team.

The following describes the steps in developing a well-defined specification. Like any methodology, the purpose is to obtain all the required information, synthesize it, and produce the desired outcome. Poor specification development can result in time delays for revision, vendor-buyer conflict over interpretation, and ill-suited processes.

***Involvement of a cross-functional team:*** The first step in specification development is forming a cross-functional team of the affected business functions. This group includes manufacturing, product design, industrial engineering, plant management, operators, maintenance, electrical design, information systems, and finance. The manufacturing engineering function takes the lead role in specification development, with the other functions providing input when required. Expertise from outside the engineering groups is required for the development of mechanical and electrical system specification, as well as in defining the standard terms and conditions of the purchase.

***Identification of system integrators:*** Having already determined expectations for the system integrators, they can be chosen from the existing Visteon supply base. The purchasing function maintains a list of equipment suppliers to be quoted for a specific type of process, so this list should be used to identify potential vendors. Plants will often have a list of vendors they have successfully worked with in the past, and who understand the plant processes and specifications. Other potential sources for a vendor list include similar processes at other plants or product lines, and vendor development programs from purchasing.

If required, the second group of vendors that must be chosen is the machine builders. Machine builders supply the individual machines that are integrated into the process by the system integrators. These suppliers can often be evaluated by finding similar machines within Visteon plants or having a visit arranged to another customer of the company.

***Develop the information to be included in the specification:*** At a minimum, the specification should include:

- A product description
- Listing of relevant business assumptions
- The proposed process order and operation
- Quality and reliability requirements
- The physical layout and locations for the process
- The program management requirements of the vendor

Many of the specification requirements are taken from the methodology's third QFD house. These should be ranked for importance during specification development, so an accurate picture of the requirements can be given to the system integrators. A benefit of the QFD approach during specification development is the resulting focus on what the line must do, as opposed to how existing lines have been designed.

***Specification Preparation:*** In developing the specification, the engineer must determine the level of detail to be provided. This should be based on the determined needs and expectations earlier in the process. Specifications for standard, off-the-shelf machines will be relatively short and high level compared to that for a large one of a kind system. Nyman (1992) lists two types of specification that may be required, functional and performance. Functional specifications place requirements on equipment in terms of dimension, sequence, interface, and capacity. Performance specifications deal with features like accuracy, tolerance, and reliability.

Traditionally Visteon engineers have listed detailed functional specifications to integrators, while supplying boilerplate performance descriptions. The performance specifications for systems and individual machines should be a function of the needs and requirements of the line. The engineer must ensure that the integrator understands the numbers behind the performance specifications to prevent problems during run-off and in production. It is quite common for the engineer to specify 85% system OEE, the vendor's response to quote certifies it, and then the resulting system doesn't meet the requirement because the line includes a high number of tightly linked 95% uptime machines.

### 3.5.4. The Advance Purchase Notice / Request for Quotation Process

The advance purchase notice (APN) / RFQ process consists of three steps: submission of the APN, facilitation of a line-up meeting, and preparation of quotations. The manufacturing engineer is responsible for the first two items in advance of the system integrators completing their quotations.

***Completion of the APN:*** The APN form is a series of computer screens the engineer must complete in the Ford system. A standardized form, the APN includes basic information regarding the system to be developed, products, expected costs, line-up meeting dates, and other required information. In addition, it includes the clauses for the plant and division regarding purchasing, documentation and other requirements. The objective of the APN is to formally notify the vendors and purchasing that a project is to be quoted, not to detail the specification and product.

Part of the APN form is a listing of system integrators or machine builders who will receive the RFQ. The vendors previously selected should be included in the APN listing, with consideration to current projects and capacity of the vendor.

***The line-up meeting:*** At the line-up meeting the engineers present the project, specification, and expectations to the suppliers. The engineers should be prepared to answer questions regarding the specification, quotation timing, project timing, and other requirements. In addition, engineering will be required to state the expectations on what type of line is desired. When new types of lines are being requested, overview or training sessions may be needed. The line-up meeting is the engineer's opportunity to explain what is wanted and expected of the integrators.

The result of the APN/RFQ process is a set of vendor proposals, including layouts, financial estimates, timing, delivery, service, and quality requirements. If requested, the proposals may have options quoted for analysis by the engineer. In addition, the vendors should be able to propose options they feel will provide a better manufacturing process.

### 3.5.5. Analysis of Proposed Concepts

Once the vendor proposals have been received, the engineering team must evaluate and select a concept. The engineer selects both the line design and vendor with this decision, so the relationship and capabilities established by the system integrators are as important as the design.

The analysis begins by listing the previously generated design requirements. Given the early stage of the process, the manufacturing engineer is not evaluating final capability, but looking for the best concept to implement. To complete this analysis, each concept is evaluated against the list of requirements, both quantitative and qualitative. The evaluation follows a three-step process:

1. Screen proposals for viability
2. Determine if the RFQ/APN is required again
3. Perform a detailed analysis on accepted proposals

***Screen for Viability:*** The analysis of proposals can be time consuming and detailed, so an initial screen is conducted to eliminate any obviously non-competitive or non-functional proposals. The proposals should be screened for feasibility from both a technical and operational perspective. This is an important distinction, since the proposed line might functionally produce a part, but will not integrate into the plant's intended operation or operator system.

***Determine if APN/RFQ needs repetition:*** If an acceptable set of proposals does not pass the initial screen, the team needs to repeat the APN/RFQ process. The first step is to identify why the proposals did not meet the team's intent. The cause must then be addressed and corrected before another attempt is made. Reasons may include changed volume assumptions, modified product designs, or an incomplete or misinterpreted specification. In the latter case, the team must address whether the correct group of vendors was quoted, or if training or a line-up meeting will resolve the problem. The confidentiality of vendor proposals must be maintained during this process, as the manufacturing equipment industry is highly competitive.

***Detailed Analysis:*** For proposals passing the initial screen, a detailed analysis should be carried out. This analysis should look at the quantitative and qualitative measures developed in the QFD process and proposed through the specification.

Where possible, this step should utilize analytical tools. The purpose of the tools is not to provide exact data, but to help the engineers understand each proposal and concept. The analysis should include the ability of each design to meet each stakeholder's needs. Capacity, capability, and reliability of the line design should be included, as well as the economic impacts of each proposal. Since designs are easily changed at this phase of the process, the engineer need only validate and understand concepts, while understanding the timing and financial implications of any required changes.

### 3.5.6. Choose a Concept

Deciding which concept to choose again uses the AHP method. Following the same process as in the system architecture choice, the team goes through the process to determine the best choice of the alternatives.

In structuring the hierarchies for the AHP process, several different approaches can be used. Arbel and Seidmann (1984) utilized a benefits and cost hierarchy in analyzing a Flexible Manufacturing System. For the benefits general criteria, they chose to divide the problem into economic, production, and organizational categories. Their cost hierarchy has two general criteria, system acquisition and system dependability. Ideally, most of the hierarchy criteria can be derived from the QFD process and the specification requirements. This process may provide the reasons for vendor selection other than the lowest bid.

## 3.6. The Line Build Stage

During the construction of the line, the manufacturing engineer has several responsibilities and obligations. Oversight of the vendor's program management, processing deviation approvals, and facilitating the relationship with Visteon are all part of the manufacturing engineer's role.

### 3.6.1. Program Management

The manufacturing engineer is responsible for the oversight of the process or equipment build. This includes regularly scheduled meetings with the system integrator to review the design, timing, status, and issues surrounding the project. Most specifications include a summary of what the vendor is expected to provide for program management. Examples include:

- Identification of key personnel
- Design review schedules
- Delivery requirements
- Payment requirements
- Vendor installation and production support
- Warranty and reliability follow-up

### 3.6.2. Disposition of Deviations

The manufacturing engineer is responsible for the disposition of deviation requests as they occur during the process. One source of deviations is vendor requests that conflict with plant equipment standards. The engineer must evaluate the cost to the plant against the potential reduction of functionality that may occur with a machine design change. Deviations may cause the plant to incur increased inventory costs for spare parts, the management of additional non-production part suppliers, and the computer and human resources required to track, store, and deliver these parts. These additional costs can be much larger than the small part cost of many pneumatic, mechanical, and electrical components.

A second source of deviations occurs from Visteon requests. These are often related to program assumptions changing during the design and build process. When changes are required, time should be taken to determine what the effect will be on the existing system and how the change should be implemented.

A final type of deviation is when the vendor cannot meet the specification or quoted proposal. These deviations are typically significant, as the vendor will usually absorb small issues to maintain their relationship with the buyer. The effect on the plant and operators must be carefully considered, as the change is a one-time effect on engineering and the vendor, but the plant will operate the process for years.

### 3.6.3. Visteon Interface for the Vendor

During the build phase of the project, the engineer functions as the interface between the vendor and Visteon. This role includes gaining approvals, acting as a source of product and process information, and facilitating any new technology development.

***Gaining approvals:*** The engineer must obtain the required design approvals by the purchasing plant. For both mechanical and controls drawings, the engineer must obtain the drawings, request reviews, transmit any problems to the vendor, and finally gain approvals. When manufacturing engineering isn't located at the purchasing plant, an important part of this process is obtaining the appropriate approvals. Each plant will have its own specifications, and approval from the wrong organization creates problems usually found during the launch phase when the vendor has a limited ability to correct the problem.

***Provide product and process knowledge:*** Any relevant information the vendor can obtain through the manufacturing engineer regarding processing and product design aids in process development. Product design requirements often include complex functional interrelationships of which the process vendor has little or limited knowledge. This requires communication from the product designer to the vendor. Any prior information from existing processes is important, including both equipment design information and plant operations procedures.

***Technology Development:*** For some lines, new technologies must be developed for implementation. These include both new means of processing products, and machine components that must be developed for an application. In the former case, the engineer must facilitate the communication between the development groups and the vendors. In the latter case, Visteon may develop relationships with machine component manufacturers and must integrate the development with the new line. For example, a producer of pneumatic seals was consulted in developing a chemical resistant product for a test station. The new seal was developed by the manufacturer, evaluated and used by Visteon, and is now part of the producer's standard catalog.

## 3.7. Run-off and Acceptance

After the new line is constructed, the final stage of the build process is run-off and acceptance to prove process control and capability. This is the demonstration and prove-out stage for the new line and is the final milestone that occurs at the vendor's facility. As such, it requires planning, negotiation, and careful execution to be of value to both Visteon and the system integrator.

### 3.7.1. Background

The conditions surrounding the run-off of a new manufacturing system create a unique situation in the relationship between the system integrator or machine builder and Visteon. The run-off is the final full tryout of the new line before it is shipped from the vendor's facility. The run-off is based on the acceptance criteria called out in the specification, and requires planning and coordination with the supplier.

The standard contract for equipment purchase specifies a 90% payment upon acceptance at the vendor's facility. This makes the run-off not only a test of the system, but a significant financial milestone. At the most base level, the vendor wants the system accepted and shipped to receive payment. Shipment is important, since a large manufacturing system can absorb a significant percentage of a system integrator's available capacity and working capital. From the perspective of the buyer, a significant amount of negotiating leverage is lost after acceptance. In most cases, continuing support is not an issue when the run-off has been successful and the system integrator wants to be considered for future business.

### 3.7.2. Views of the Run-off

***Visteon:*** In addition to the payment effects of the run-off, Visteon engineers must consider several other factors during the trial. For the operators the run-off is a training exercise, and while involved in the design stage, it may be their first chance to operate the new process. Since there will be inefficiency in the run-off as people learn their new assignments, a trial run is helpful if the costs can be absorbed.

To the manufacturing engineers and the plant, the run-off is the only chance to verify the operation of the new process. The buying plant, which deals with any unresolved issues from run-off, requires a robust, capable process. However, there is also schedule pressure on most run-offs to meet the timing requirements of the vehicle or product program.

***The system integrator:*** The system integrators have a number of conflicting views of the run-off process. The run-off is the last opportunity to fix any problems on site, where the integrator is most capable to resolve issues. After shipment, vendor technicians work with the buyer during installation and de-bug, but have a limited ability to make changes or work on the equipment. Competing with the ability to resolve equipment issues, the run-off is the vendor's last hurdle before payment of a large percentage of the fee. It is therefore a business benefit to get acceptance of a line.

Another vendor issue with run-off is that the acceptance criteria are often considered arbitrary or out of the vendor's control. The production parts used in run-offs may be prototypes and out of specification, which may cause process throughput problems. When Visteon operators run a line for the first time, their lack of familiarity with the equipment may reduce system OEE. Finally, the acceptance criteria often include issues pertaining to the physical arrangement of the buying plant, which are often not understood by the system integrators. These support facilities may include air, gas, electrical, or water hookups, or may be operating parameters like how the

CIM system interfaces with the line. These issues should be addressed in the specification to ensure everyone understands how the run-off is to be performed.

### 3.7.3. Objectives of Run-off

The manufacturing engineer has four basic objectives to accomplish at run-off:

- Match intended production as much as possible
- Achieve OEE performance
- Prove product and process control and then capability
- Verify the controls logic

Getting the run-off to replicate the plant operations as much as possible not only helps prove out the process, but also tests the ability to operate in the buying plant's environment. This includes attempting to match the location and delivery of production parts, operator stations, floor layout, and operating pattern. While it is impossible to replicate the system exactly, deviations should be noted and attempts made to ascertain if problems exist.

Product and process control and capability are important factors in the run-off process. Process control must be shown before any measure of capability can be taken. Product quality, which is measured in Cpk, must be studied to determine capability and not the absence of defects. A good system integrator is comfortable with this concept and will agree to it as part of the specification. Again, prototype parts that do not meet print will cause problems with measuring product quality. Process capability proves the line will operate as promised over several shifts, and then months at the buyer's facility.

As manufacturing systems become more complex and integrated, the prove-out of the controls system is becoming more important. Expertise in controls is an important criterion in vendor selection, and successful prove-out is required for a seamless launch. There are four aspects to controls: CIM integration, system control logic, machine control logic, and controls components. Prove out of a CIM system is difficult on the vendor's floor, but, where possible, all data gathering at run-off should be taken from the CIM system. The system control logic is typically a complex set of programs and information passed between different controllers in the process, and requires a large amount of debugging to operate correctly. These systems are so complex it is very difficult for an electrician in a Visteon plant to understand and debug them during production. Machine logic relates to the individual controllers operating each station of the process. Controls prove-out is not a well-defined process due to the almost infinite possible combination of factors that can affect programs in a large manufacturing system. As a result, vendor controls support, training, and upgrades should be written into the specification as a part of the launch process.

### 3.7.4. Run-off Methodology

A four-step methodology is proposed for the run-off and acceptance phase of a process.

1. Define and agree on acceptance criteria for the process
2. Complete the run-off
3. Analyze the results. If not acceptable, go to step 1
4. Accept the process and ship to the purchasing plant

***Acceptance Criteria:*** The acceptance criteria reflect include the requirements written into the specification and any factors that have changed during the build phase. Well before the run-off date, the manufacturing engineers should establish the acceptance criteria for the prove-out. This involves the specification requirements, changes due to the deviation, the roles of operators and maintenance personnel, and how the data will be taken and evaluated. The agreed upon criteria will be used to accept the system and act as a reference for issues that may come out of the run-off.

***Complete the Run-off:*** The actual run-off should be completed according to the specified parameters. During the run, the engineer must pay attention to the data collection systems and operator jobs to ensure they have been properly defined, and to detect and correct any problems.

***Analyze the Results:*** During and after the run, the process data should be reviewed for acceptability. Should there be major problems, such as processing or product quality issues, the run should be ended and the problem corrected. The analysis of run-off results often includes incorporating external factors like out-of-print prototype parts and incomplete systems. It is up to the Visteon team to determine how to treat such occurrences, but if a problem was seen in run-off, it is highly probable it will surface again on the plant floor if the root cause is not eliminated.

***Accept and Ship:*** Each division of Visteon typically has their own sign-off sheet for a new process. At a minimum it includes approvals from engineering, safety, plant operations, ergonomics, controls, and mechanical design.

## 3.8. Chapter Summary

This chapter described a proposed design methodology for manufacturing processes. The differences between process and product design methods are discussed, as is the approach taken for the research. The methodology includes designing systems for the equipment, plant management, operators, supply chain, product design, and customers as stakeholders in the line. The first step in the process is project definition, followed by system architecture design, detailed design, and the build, run-off, and acceptance stages. A significant part of the process is understanding the relationship, expertise required, and incentives involved with the system integrator manufacturing the equipment.

# 4. Applications of the Design Methodology

This chapter shows four examples of how the proposed design methodology affects the process of developing new manufacturing lines. The project definition example shows analysis performed for an electronic module line being developed. The other examples are ex-post analyses of existing processes within Visteon to show how the design methodology would benefit the process.

## 4.1. Project Definition: The Electronic Module Assembly Process

Visteon facilities produce electronic components for a variety of OEMs vehicle lines, including Ford. The plants produce sensors, control modules, and other electronic modules used in automobile electrical systems. The typical plant runs a variety of processes including Surface Mount Device (SMD) placement and solder, module assembly, and test operations.

In the past, the manufacturing operations have worked closely with product design to keep the product configuration consistent within the electronic module families used by Ford. With changing automobile customers and global market requirements, product design has recently moved away from the common size and shape by adding a smaller and larger version to a product family. The new module applications are low volume, diverse product design programs that the plant has not had to manufacture in the past. These new products raised concerns with material flow through the existing automated lines, so the plant decided to investigate designing a separate process.

***Method:*** To ensure a broad perspective, a cross-functional team including manufacturing engineering, industrial engineering, production management, and advanced manufacturing was formed. As shown in Table 4, the team first created a project definition sheet based on the method given in section 3.3. The resulting project definition page included input from the project assumptions, stated management strategies, and existing process knowledge.

**Table 4: Module Project Definition**

| Process Description | Module Assembly Cell Design |
|---|---|
| Product Description | Electronic Modules, standard plus two new form factors |
| Key Business Goals | • Meet Annual Volume<br>• Minimize Total Costs<br>• Optimize FPS Measurables<br>• Maximize Flexibility<br>• Utilize Existing Equipment |
| Manufacturing Strategy | • Move to lean manufacturing in final assembly and test |
| Process Identification | • "Front End" - SMD standard configuration<br>• "Back End" - Assembly and test equipment in a cellular layout |
| Assumptions | • Current assembly process steps maintained<br>• Existing SMD lines utilized<br>• Standard plant shift operation |
| Stakeholders | • Customer plants<br>• Plant management<br>• Operators<br>• Component Suppliers, SMD lines<br>• Product Designers<br>• Equipment Manufacturers |

Adapted from Ulrich and Eppinger (1993)

***QFD Needs Analysis***: After completing the project definition phase, the team developed a needs list and applied the QFD process. The needs list begins with the FPS Principles, and then considers plant, product design, operator, line design, and customer needs. The group initially completed one large QFD, ignoring the system level/detailed level classifications to analyze any interaction effects between the characteristics. After the initial QFD was completed, it was broken into the respective system architecture and detailed design houses for further analysis, as shown in Figure 9 and Figure 10.

Within Figure 9, total cost is an FPS measurable calculated by summing labor, equipment, quality, shipping, inventory, and other production system costs. Total cost is different from traditional accounting analysis, which emphasizes labor efficiency and allocates other costs to different functions. Unit cost is then the total cost divided by the production volume. This total system focus is intended to develop more efficient production processes for the company, rather than optimizing the various sub-processes.

## Figure 9: Electronic Module System Level QFD

| | 0 Defects made first time through | 0 Defects passed on first time through | FPS dock-to-dock time objective | Order to delivery score | Build to schedule | Build to market demand | Minimize cost per unit | FPS OEE objective | Work Cell Replication | Vary the number of operators | Standardize work and operator loops | Utilize Integrated Manufacturing Tean | One machine per operation | Line of sight layout | Bring operators in early for training | Double value added time % | Double value added space % | Minimize $ / unit of capcity | System response < D interval |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FPS Principles** | | | | | | | | | | | | | | | | | | | |
| Zero Waste / Zero Defects | + | + | + | + | + | | | | | - | | | + | | | | | | |
| Align Capacity to Market Demand | | | | | + | + | | | + | + | | | | | | | | | |
| Optimize Production Throughput | | | | | | | | + | | + | | | | | | | | + | |
| Use Total Cost as a Driver | | | | | | | + | | | | | | | | | | | + | |
| | | | | | | | | | | | | | | | | | | | |
| **Plant** | | | | | | | | | | | | | | | | | | | |
| Volume Flexibility | | | | | | + | | | | + | + | - | | | | | | | |
| Create Predictable Output | | | | | + | + | | + | | | + | | - | | | | | | + |
| Prevent Changeover Disruption | | | | | | | | | | | | | - | | | | | | |
| Prevent Material Stocking Disruption | | | | | | | | | | | | | | | | | | | |
| Minimize WIP | | | + | | | | | | | | | | | | | | | | |
| Eliminate Excess Inventory | | | + | | | | | | | | | | | | | | | | + |
| | | | | | | | | | | | | | | | | | | | |
| **Line Design** | | | | | | | | | | | | | | | | | | | |
| Minimize Investment Cost | | | | | | | + | + | + | - | | | + | | | | + | + | |
| Maximize Value Added | + | + | | | | | | | | | + | | | | | + | + | | |
| Meet Capacity Requirements | | | | | | | | + | | + | + | | | | | | | | |
| One Piece Flow | | | | | + | + | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| **Operator** | | | | | | | | | | | | | | | | | | | |
| Effective Communication | | | | | | | | | | - | | + | | + | + | | | | |
| | | | | | | | | | | | | | | | | | | | |
| **Customer** | | | | | | | | | | | | | | | | | | | |
| Able to Respond to Changes | | | | | | | | | | | | | | | | | | | + |
| 0 Defect Received | + | + | | | | | | | | | + | | | | | | | | |

The left hand side of the QFD lists the brainstormed customer needs and FPS principles for the manufacturing process. The top row lists metrics and means of achieving the needs in the system architecture design. Within the matrix, a (+) signifies a positive relationship between the intersecting row and column, a (–) signifies a conflict or negative relationship.

## Figure 10: Electronic Module Detailed Level QFD

| | Safety & Health Assessment | Design volume flexibility by changing # of operators | Develop standardized work sheets | Design so operators perform changeovers | Line of sight layout design | Stations utilize visual factory guidelines | Bring operators in early for training | reduce non-form factor changeover time 30% | reduce form factor changeover time 30% | Minimize WIP in process | Universal test connectors | Removeable fixtures | Manual load stations | Specify plant Safety Guidelines | Each station designed with in station verification | Station fault stops machine | Utilize one machine per operation | Test is a paypoint | ICT is a paypoint | Programming is a paypoint | Pack is a paypoint | 1 piece buffer between stations | Minimize buffer after SMD | Utilize standard machines | Specify OEE for each station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FPS Principles** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Effective Work Groups | + | - | + | + | + | + | + | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Product Design** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Accomodate 3 form factors | | | | + | | | | + | + | - | + | + | + | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Operator** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Safety | + | | | | | | + | | | | | | | + | | | | | | | | | | | |
| Culture of Continuous Improvment | + | - | + | + | | | + | | | | | | | | + | + | | | | | | | | | |
| Operator Acceptance | + | - | | + | | + | + | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Line Design** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Design for Reliability & Maintainability | | | | | | | | | | | | | + | | | | | | | | | | | | |
| Part Traceability | | | | | | | | | | | | | | | + | + | + | + | + | + | + | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
| **From System Level QFD** | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 Defects Made First Time Through | | | + | | | | | | | | | | | | + | + | | | | | | | | | |
| 0 Defects passed on | | | | | | | | | | | | | | | + | + | | | | | | | | | |
| FPS dock to dock time objective | | | | | | | | + | + | + | | | | | | | | | | | | + | + | | |
| Build to schedule | | + | + | | | | | + | + | + | | | | | | | | | | | | | + | | |
| Build to Market Demand | | | | | | | | + | + | | | | | | | | | | | | | | + | | |
| Minimize Cost per Unit | | + | + | + | - | | - | | | + | - | - | + | | | | | | | | | | | + | |
| FPS OEE objective | | | | | | | | + | + | - | | | + | | | - | - | | | | | | | | + |
| Vary the number of operators | | + | + | | | | | | | | | | | | | | | | | | | | | + | |
| Standardize work and operator loops | | + | + | | | | | | | | | | | | | | | | | | | | | | |
| Implement IMTs | + | - | + | + | + | + | + | | | | | | | | | | | | | | | | | | |
| Double value added time % | | | | | | | | | | + | | | | | | | | | | | | + | + | | |
| Double value added space % | | | | | | | | | | + | | | + | | | | + | | | | | + | | | |
| Minimize $ / unit capacity | | | | | | | | | | | | | + | | | | + | | | | | + | | + | |
| System Response < D int | | + | | | | | | + | + | + | | | | | | | | | | | | + | + | | |

***Results:*** The project definition phase of the methodology provided two benefits to the process design team. First, the QFD process brought out several issues that had not been considered by the team in the initial planning for the process. In analyzing Figure 9 and Figure 10, several negative relationships were found between needs in the left hand column, and the implementation means along the top.

- Varying the number of operators may make teamwork difficult. The analysis indicated changing the number of operators to obtain volume flexibility would potentially induce tension in the cell work team. Specifically, it would be an issue in developing a culture of continuous improvement, obtaining operator acceptance, and in implementing Integrated Manufacturing Teams (the work team concept at the plant).

- There is a conflict between minimum investment and the extra machine capacity required in the cell design. Since a cellular approach designs for the operators as the process constraint, by definition excess machine capacity will exist. Given the plant's expectation of high equipment utilization, the team recognized that a work cell would have some unfavorable comparisons to an automated line.

- An assembly cell alone may not gain the benefits of a synchronous system. Since the cell would receive parts from a traditional functional SMD department, there would be no synchronization between lines and buffers would have to be used.

- One machine per operation may reduce system uptime. Traditional lines in the plant often have multiple machines in parallel to meet the high volume requirements. Thus, when a machine went down, the line could still meet some of its volume. The cellular concept would eliminate this benefit, requiring a new focus on maintenance and operation. This effect is shown in Figure 10, with the negative relationship between the FPS OEE objective and utilizing one machine per operation.

The other benefit of the methodology's QFD process was that it facilitated communication within the design team. By taking a structured approach to dealing with line, product, supply chain, customer, operator, and plant issues, the team was able to discuss each point without one person's issues dominating.

***Reflections on the Process:*** Overall, the methodology's QFD approach worked well to define the needs of the process for the new module line. The process can be improved by addressing the facilitation, timing, and method of using this approach. First, a known team leader should be present during the process to keep the group on track and address questions regarding the direction and strategy of the new line. In this example, the process was used early enough in the design to be open to different design requirements. The facilitation process could be improved by having introductory materials given to the team in advance, as the distinction between system level effects and detailed level effects was confusing in the development of the methodology's QFD.

## 4.2. System Architecture Design Example – Instrument Panel Manufacturing[1]

This section provides an example of the System Architecture phase (see section 3.4) of the methodology. It is an analysis of an Instrument Panel (IP) line designed for one of Visteon's Interior Systems Plants. This section provides an analysis to show the value of a system level review.

Currently, the manufacture of an instrument panel follows one of two processes based on the product design. A hard panel, which includes this product, is a painted injection molded IP substrate with the cross-car beam, ducting, and wiring assembled to it. The process for a hard panel includes injection molding, painting, assembly, and then packing and shipping. A soft IP assembly involves molding an IP substrate, applying a cover, and filling the gap between the cover and substrate with a foam before painting and assembly. Other than color, which is managed at the molding and paint processes, complexity is added during assembly with no significant changeover time involved.

The plant management and manufacturing engineering section developed three objectives for this process, based on FPS principles and other plant initiatives. First, the plant wanted to implement continuous flow manufacturing to minimize in-process inventories. Second, the line needed enough capacity to build 250,000 units per year. Finally, the plant wanted to have no in plant storage of cross-car beams or finished goods. The dunnage for the cross-car beams, a purchased part used early in the assembly process, and the finished IP assemblies was to be taken directly from a truck to the line, and then returned to the truck.

### 4.2.1. Determination of System Level Architecture

***Process Requirements:*** Since this IP is a hard panel, the process requirements were determined by the product design and included injection molding, painting, and assembly. These processes are standard at the plant, as it produces several IP products for other vehicle lines. Two press sizes are required to injection mold the parts. The IP substrates are to be molded on the plant's large presses; and the glove box doors, glove box bins, and ducts are to be molded on smaller machines. The paint operation for the IP substrates and doors is also a standard process

[1] Volume, capacity, and operating pattern data have been disguised. The data are given to illustrate the analysis of a proposed process design.

for the facility. Finally, the assembly operation requires only one new feature compared to the existing lines, an ultrasonic weld of the duct moldings. This is a standard manufacturing operation, posing no technical risk or significant investment.

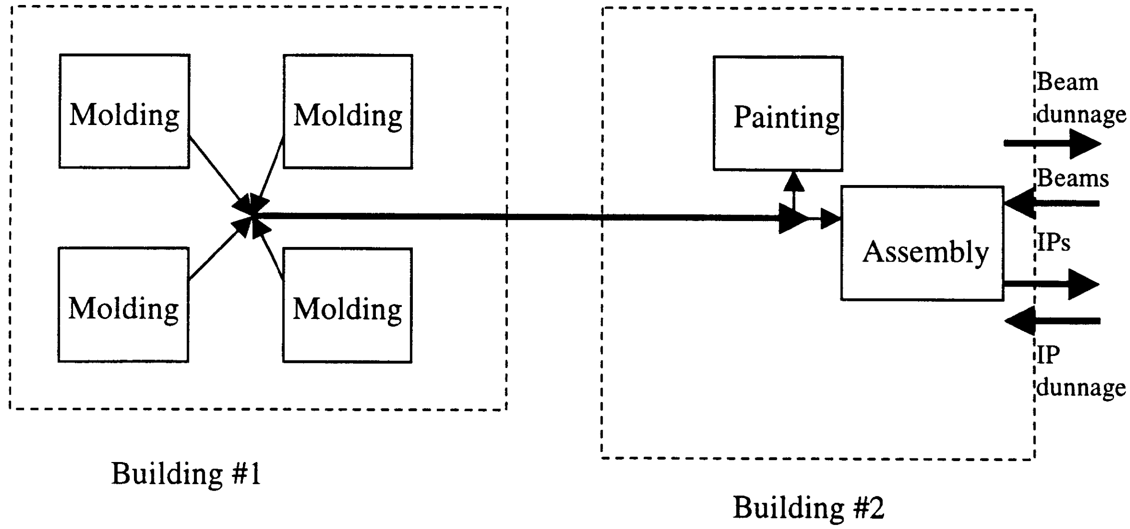
***System Flow:*** In analyzing the IP line design, there are several significant factors in the flow of material through the plant. The first is the layout of the equipment. The initial intent was to place the molding presses beside the painting and assembly equipment, which became impossible because the assembly area floor could not support the machines. The layout was modified to put the presses with the rest of the facilities' injection molding machines in the building next door. To implement the continuous flow strategy, non-accumulating chain conveyors were proposed to transfer molded parts to the paint and assembly area and to move parts through the paint line. The large distances to be traveled would result in parts taking one hour on each conveyor. The glove box doors were not to be put on the molding conveyor, but instead transferred by forklift from the molding area to the beginning of the paint line.

The plant planned a two shift, five day per week operation for the entire IP line. This strategy was used to eliminate the need for the traditional buffering in front of IP assembly. In most lines, the capital intensive molding machines are run 24 hours a day and the faster paint and assembly lines only run 16 hours, resulting in WIP buildup on the off shift. To implement continuous flow, the paint and assembly lines were designed to operate at a process time near that of the molding machines, synchronizing the entire process to prevent WIP accumulation.

Finally, the shipping and receiving location was important to the flow of material. New docks were placed beside the assembly line so finished IPs could be immediately loaded onto trucks. Similarly, docks were built to immediately unload cross-car beams onto the assembly line.

The system layout resulted in:

**Figure 11: IP Process Layout**




***Process Selection:*** Given the high level of standard processes required, the plant had straightforward choices for molding and assembly. The paint line was seen as a potential quality and throughput risk, however, and was given more consideration. The plant considered manual and automated spray systems for the line, finally choosing the automated system. This was done for faster changeover time, more consistent spraying, and to avoid having operators go through the difficult motions required in painting.

***Capacity Analysis:*** The plant capacity objective was analyzed using a traditional capacity analysis, focusing on the process times, scrap rates, and available time of the equipment. This analysis showed the system design had more than enough capacity to meet the goal of 1042 Instrument Panels a day:

## Table 5: Molding Capacity Analysis

| Molding Capacity | IP | Glove Box Door | Glove Box Bin | Duct |
|---|---|---|---|---|
| Tools | 3 | 1 | 1 | 1 |
| Process Time | 100 | 75 | 75 | 75 |
| # of Cavities | 1 | 2 | 2 | 2 |
| Scrap Rate | 3.0% | 3.0% | 3.0% | 3.0% |
| MTBF (Hours) | 40 | 40 | 40 | 40 |
| MTTR (Hours) | 3.5 | 3.5 | 3.5 | 3.5 |
| Changeovers / day | 0 | 3 | 0 | 0 |
| Changeover Time (Hours) | 0 | 0.5 | 0 | 0 |
| Available Time (Hours) | 16 | 16 | 16 | 16 |
| Net Available Time (Hours) | 16 | 14.5 | 16 | 16 |
| Up Time (Hours) | 14.7 | 13.3 | 14.7 | 14.7 |
| Net Daily Capacity | 1541 | 1242 | 1370 | 1370 |
| Required Capacity | 1042 | 1042 | 1042 | 1042 |
| **Planned Capacity Utilization** | **68%** | **84%** | **76%** | **76%** |

## Table 6: Paint Line Capacity Analysis

| Painting Capacity | IP | Glove Box Door | Total |
|---|---|---|---|
| Net Parts Input | 1042 | 1042 | 2084 |
| Parts / Conveyor Hook | 1 | 6 | |
| Required Hooks / Day | 1042 | 174 | 1216 |
| Time / Hook (Seconds) | | | 30 |
| MTBF (Hours) | | | 4 |
| MTTR (Hours) | | | 0.25 |
| Changeovers / Day | | | 3 |
| Changeover Time (Hours) | | | 0.33 |
| Available Time / Day (Hours) | | | 16 |
| System Uptime / Day (Hours) | | | 14.1 |
| Available Capacity | | | 1688 |
| **Planned Capacity Utilization** | | | **72%** |

**Table 7: Assembly Line Capacity Analysis**

| Assembly Capacity | |
|---|---|
| Required Parts / Day | 1042 |
| Process Time (Seconds) | 30 |
| Changeovers Required | 12 |
| Changeover Time | 0 |
| MTBF (Hours) | 12 |
| MTTR (Hours) | 0.67 |
| Available Time / Day | 15.2 |
| **Available Capacity (Parts)** | **1818** |

From the traditional capacity analysis, the plant assumed continuous flow manufacturing could be implemented since the process had excess capacity. For this purpose, little space was left in the layout for part storage after the molding to paint line conveyor and between the paint line conveyor and the assembly line.

***Continuous Flow Analysis:*** To examine if the system could produce the desired continuous flow without buffering, an analysis of the effects of variability on the system was performed. Due to the capacity utilization of the equipment and the average length of breakdowns, the process dominating the system is the injection molding operation. Since non-accumulating conveyors were used, the distribution of interarrival times at the paint line would match the distribution of departures from the molding process. The molding operation can then be analyzed for variability resulting from breakdowns and changeovers, as presented by Hopp and Spearman (1996).

<u>Breakdowns:</u> From the initial analysis, one might assume the system could easily meet the required capacity. Based on the analysis in Table 5, the glove box door machine is 84% utilized while in operation 13.3 hours per day. This conclusion ignores that in the proposed system, when a molding machine goes down the rest of the molding machines would have to be shut down because the layout does not provide for significant buffer accumulation. As a result, the system downtime would be higher than the capacity analysis indicates. The variability effects

of breakdowns can be seen by examining the squared coefficient of variation of the effective process times ($c_e^2$) of the molding machines:

**Table 8: Molding Variability from Breakdowns**

| | IP | Ducts | Doors | Bins |
|---|---|---|---|---|
| Process Time($t_o$) (Seconds) | 100 | 75 | 75 | 75 |
| MTTF (Hours) | 40 | 40 | 40 | 40 |
| MTTR ($m_r$)(Hours) | 3.5 | 3.5 | 3.5 | 3.5 |
| Availability (A) | 92% | 92% | 92% | 92% |
| $c_e^2 \approx 2A(1-A)(m_r/t_o)$ | 18.64 | 24.73 | 24.73 | 24.73 |

The breakdown analysis ignores the variation from molding machine process time, which is insignificant compared to the process time and MTTR. From the scales given by Hopp and Spearman (1996), which classify variation by the magnitude of the coefficient of variation:

**Table 9: Classification of coefficient of variation**

| | |
|---|---|
| Low Variation | CV < 0.75 |
| Moderate Variation | 0.75 < CV < 1.33 |
| High Variation | 1.33 < CV |

The squared coefficient of variation values resulting from the molding operation show the system can expect a high amount of variability in part arrivals from the presses.

Setups: The one press requiring setups during the day, the door press, has to change colors three times each day. Each changeover takes an average of 30 minutes to clear and refill the press. This changeover requires the paint line to hold 30 minutes of glove box doors of the prior color to continue to make Instrument Panels while the molding operation changes over. Should the buffer not be held, Instrument Panels would build up in the system, which are larger and more difficult to store than the glove box doors.

**Table 10: Variation Effects from Setups**

| | Doors | Paint |
|---|---|---|
| Process Time (Seconds) | 37.5 | 30 |
| # parts between setups | 348 | 348 |
| Time of setups (seconds) | 1800 | 1200 |
| Effective Process Time ($t_e$) (Seconds) | 42.67 | 33.45 |
| Effective Process Time Variance ($\sigma_e^2$) | 9542.21 | 4384.66 |
| $C_e^2 = (\sigma_e^2 / t_e^2)$ | 5.24 | 3.92 |

Conclusions: While the implementation of continuous flow manufacturing would improve the efficiency of the plant, a brief analysis shows the concept can not be implemented by changing the layout of existing machinery. The implementation of a near zero WIP system requires very reliable processes, which do not have large downtimes in relation to their processing time. The proposed line required revision to accommodate the necessary buffers to maintain the customer's required daily demand. A detailed discrete event simulation of the process was conducted, revealing a required maximum buffer of approximately four hours of IPs before the paint line to ensure 1042 parts per day.

A second problem found in the system analysis was ignoring the design of information flows. Due to the long conveyors, operators at the paint line would have no idea what part mix was coming, or if the molding machines could be shut down due to full buffers or paint line downtime. A secondary issue to the lack of buffer space, the incomplete information system is also a problem for the IP line design.

***No beam or finished goods inventory:*** The final priority for the plant involved not holding cross-car beams or finished instrument panels in inventory inside the plant. To resolve this issue, dedicated loading docks were placed next to the assembly line, with room for the reusable dunnage beside the line.

The proposed layout met this requirement. The loading docks eliminated the need for the loading, transporting, and storage of parts inside the plant, freeing valuable floorspace. The layout also gives the plant if the capability, if required by the customer, to sequence production with the assembly plant.

## 4.3. Detailed Design Example – Automotive Compressor Line

This section describes an example of the detailed design phase of a proposed automotive compressor line at Visteon. The relationship between the Visteon manufacturing engineers and the system integrators is described to highlight some of the challenges in developing manufacturing processes that do not replicate concepts previously used by the product family.

### 4.3.1. Project Background

This example involves an automotive compressor project with significant differences from the existing product family. The compressor is a component designed and manufactured by the Climate Control Systems Division of Visteon, and is used to drive the air conditioning system of a vehicle.

The new compressor was to be launched as a low volume pilot application. Because it was a new design, the program volumes reflected the risk of a new product compared to the designs currently in production. The compressor line had no firm customer applications at project definition, which added risk and timing uncertainty to the project.

Typically, a compressor line within Visteon is targeted for several vehicle lines, resulting in annual volumes in the millions of units. This has resulted in most manufacturing lines being automated, capital intensive applications driven to minimize variable costs. The new compressor application could not economically follow the high volume model of production. The uncertainty of final customers required a process able to adapt to volume and product mix changes. After initial quotations for automated lines proved too expensive, the manufacturing engineering group decided to request quotations for a cellular manufacturing approach for both the machining and assembly processes.

The objectives for the project were to:

- Implement volume flexibility via the labor force
- Minimize the work in process
- Reduce dock-to-dock time
- Lower investment costs for adding capacity
- Improve “first time through” quality levels over existing products

### 4.3.2. The Manufacturing Cell Quotation Process

In developing the cellular design project proposals, the manufacturing engineers followed the traditional process for line development. After developing a detailed specification for a manufacturing cell, the team selected a group of system integrators who had developed processes for compressors and similar products in the past. There were two groups chosen: one for the machining process and one for assembly.

In developing the machining and assembly concepts and specifications, the manufacturing engineers had involved outside resources in cellular design, benchmarked existing cellular and flexible manufacturing processes, and developed guidelines for the design of cellular lines. Since the implementation of cells was a new concept to the engineering group, a large amount of learning and training was involved in the specification development. Within this part of Visteon, there had been no existing expertise in cellular manufacturing.

The initial assembly process cellular quotations showed no cost or performance benefit over automated lines. The resulting proposals contained complex automated machinery and material handling systems, in contrast to the requested manual and semi-automatic machines that had been specified. The system integrator's proposals did not meet the cellular guidelines and resulted in the need to reiterate the assembly quotation process.

The machining suppliers, who had been exposed to cellular manufacturing from other industries and projects, returned quotes for well defined manufacturing cells. The vendors took the list of required operations and developed manual load/automatic unload operations for the process as was requested in the specification. This difference highlights an important consideration in process development, that of understanding the capabilities of the chosen system integrators. In this case, the assembly system integrators were not able to pick up the new concept, develop it, and return an acceptable design proposal. Instead they developed automated lines in a cellular U shape, without considering the specified machine guidelines. In fact, given the time constraints involved in the quotation, they added cost to the quotation to balance the risk of developing an unknown type of process.

### 4.3.3. Quotation Iteration

Since the assembly proposals were not acceptable solutions, the assembly system manufacturing engineers had to repeat the quotation process. The second quotation was modified to include several steps to improve the results, including training, a change in expectations, and the use of simulation.

Regarding training, the Visteon manufacturing engineers went back to the system integrators and provided training and clarification on the cellular manufacturing guidelines. This involved explaining the intent of the guidelines and how the system was to operate. The traditional relationship with the system integrators constantly affected the way the training and iteration process developed. When faced with uncertainty and thus risk of a line not working, the system integrators attempted to build exactly what was specified without improvement.

A second result of the initial quotations was a change in expectations. The manufacturing engineers began reviewing quotations looking for the best design, based on the most improvement potential. The engineers evaluated the system integrators by their willingness to innovate and develop a new concept rather than the quality of their design proposals.

Finally, the engineers utilized discrete event simulation to verify design concepts. Simulation was not entirely effective in the design process, but showed the importance of using analysis tools to evaluate designs. The models provided verification of throughput and resulted in the refinement of several machining and assembly design layouts. More detailed analysis led to unique layout concepts combining product flows and efficient operator assignments. The problem with simulation was the length of time required to develop each model, since the design proposals often changed before a study could be completed. Another issue was simulation required an analyst not on the core team to do the modeling. This resulted in less communication and insight than would occur if the manufacturing engineers used the tool.

### 4.3.4. Detailed Design Summary

The compressor project has two implications for the use of the methodology. While the process actually used resulted in an acceptable process design, it involved iteration of the quotation phase and delays in launching the process.

***Determining expectations of the system integrators is important.*** Because the Visteon engineer's expectations of the system integrators were never explicitly stated, they did not recognize the problems with developing manufacturing cells. The engineer's expectations, which included improving a cellular design concept, may have led to the selection of a different set of equipment suppliers, or at least allowed for planning of the training and development steps that resulted.

***Specification iteration is costly in time and effort.*** By having to iterate through the quotation process several times, the project timeline was extended. The system integrators had to revise and present several different design concepts while learning what the engineers wanted. A specification that met the desired cellular design while written for the level of integrator's expertise would have saved time and effort. A better solution would have been to identify qualified system integrators who had experience with cellular design and the existing processes and products.

## 4.4. Fuel Pump Assembly Line – Line Build and Acceptance

This section describes the build and run-off stage of a Visteon fuel pump assembly line. The example highlights the importance of the manufacturing engineer relating product and plant knowledge to the system integrator building the new process. This example also shows the importance of negotiating acceptance criteria for the process, and properly evaluating the results during and after the run-off.

### 4.4.1. Background

Visteon is in the process of expanding its fuel pump manufacturing capacity worldwide. The current product is a turbine based pump design, which uses a different technology than the previous positive displacement pump. The turbine design, while more robust with fewer parts and better performance, requires a different set of specifications to manufacture given the very tight tolerances involved with the product. From the plant perspective, the process changes very little, as the same types of assembly systems are used with modifications to the assembly tooling.

With this in mind, the system integrator chosen for this product had prior experience with fuel pump assembly work, but not with this specific design. The desired system, an asynchronous loop, is the type of process in which the integrator specialized so the choice of supplier matched the expertise required.

### 4.4.2. Product Knowledge Effects in the Build Stage

During the line build stage, the manufacturing engineer acts as a knowledge resource between Visteon and the system integrator. While the integrator has expertise in equipment integration, the engineer has a better understanding of the product, plant, operator, customer, and supply chain requirements. In the build stage, product knowledge is important since detailed tooling changes are made as the integrator's toolmakers and engineers find problems with the initial detailed design.

In this case the manufacturing engineer spent a significant amount of time on the integrator's floor with the toolmakers building the line. At several points during the build, tooling changes were made that appeared to work with the product component prints, but would cause capability problems with the assembled product performance. An example of this included designing support locations for a bearing press, where the receiving component required extra support to maintain the machined taper of an adjacent surface. Loss of the taper would be undetectable by the assembly line and only show up in final product testing. This knowledge was a result of prior experience by Visteon on another line and was information the system integrator had no means of obtaining outside of time consuming trial and error.

### 4.4.3. The Importance of Line Acceptance Criteria

For the fuel pump line, the acceptance criteria were established based on the requirements in the initial specification. Calculated capability was used to determine quality levels with the requirements stated in the specification. The quality levels were to be kept, analyzed and reported on over the course of a two day run.

During the first day of the run-off, the capability levels of the line did not meet the requirements even though no out of specification parts were produced. This analysis led to several changes in the run-off. First, the trial was stopped to correct the non-capable process. Second, the run was rescheduled to ensure a complete run-off.

While these results seem intuitively obvious, the differing interests in a run-off may lead to different outcomes. Enforcing product capability upon a system integrator becomes difficult if the production parts are prototypes and are not capable in dimension or are from two different production processes and have different dimensional distributions. This is a common occurrence with prototypes and the engineer must then decide how to evaluate the integrator's process. For the fuel pump example, the integrator's responsibility for product quality was an explicit requirement that saved analysis and negotiating time during the run-off.

## 4.5. Chapter Summary

This chapter reviewed four examples of how the proposed methodology would affect the design process for manufacturing systems. The QFD process was used to complete the process definition phase, and to systematically review the requirements of a new line. The second example showed how a system level analysis could aid process design and help identify potential problems. The tools proposed in Chapter 5 are intended to help in this type of analysis. The system level example also highlights the importance of selecting an architecture that matches a plant's existing equipment and operations. A review of a detailed design phase was given, including the importance of selecting the proper system integrators for line design. The intent of the methodology is to aid the selection process by defining specific requirements and expectations. A process build stage example was reviewed to demonstrate the importance of transferring product knowledge to the system integrator and developing explicit acceptance criteria for the run-off.

# 5. Analysis Tools for Process Development

The development of a toolset for process design involved a series of steps to identify tool requirements, users, and applications. Tool requirements were identified by interviewing the Operations Engineering section about the projects and expertise they have found useful. Manufacturing engineers were interviewed to identify their requirements in design tools and how they would use them. From this review a set of tools was identified for use with the design methodology.

## 5.1. Operations Engineering Analysis Requirements

The first step in developing a proposed set of tools was to generate a list of analyses required. The Operations Engineering Section was interviewed to categorize the types of analysis they found important and useful in performing their improvement projects. The intent of this exercise was to determine the analysis manufacturing engineers should be performing to ensure good process designs. The types of analysis currently performed by the OE group include:

- Capacity Analysis
- Buffer Sizing to optimize throughput
- Reliability Analysis, including MTBF, MTTR, and quality tradeoffs
- Material Flow through a plant
- Scheduling rules for operations

The Operations Engineering section adds value to projects by taking a system level view of the problem within a plant or supply chain. To develop an effective set of tools, system level issues must be incorporated for the benefit of the manufacturing engineers.

## 5.2. Needs of the Manufacturing Engineers

The interview data from the manufacturing engineers was analyzed to determine a list of needs regarding line design. The engineers interviewed work on a wide variety of processes, including electronics, fuel components, instrument panel assembly, injection molding, and sensor manufacturing applications. They have various levels of experience in process design, ranging from 2 years on their first project to technical specialists with over 10 years experience in buying and designing manufacturing processes for Visteon.

**Table 11: Engineer's Design Tool Needs Analysis**

| Statement | Interpreted Need |
|---|---|
| Simulation isn't helpful, it takes too long for a study | Tools produce analysis results quickly, including the time to design and program the model |
| The entire system design changed since we ran the simulation | Tools are flexible enough to adapt to new designs |
| Simulation is mostly used as a verification and sales tool | 1. Tools must accurately answer the analysis questions<br>2. Visualization is important in a design tool |
| I don't have time to take a Witness class | Tools must be easy to learn |
| I should be able to click around for a couple of hours and figure the tools out | 1. The user interface should be intuitive and easy to understand<br>2. An engineer should be able to learn how to use the tools without formal training |
| I need to have help available for analysis tools | User support is required for engineer's analysis tools |
| We had the University of Michigan do a study to understand buffer sizes and placement. | Analytical buffer sizing is required in line design |
| | Detailed Operations Research concepts must be imbedded in the tool |
| There isn't enough reliability analysis done, nor is it well understood. | Reliability analysis tools have to guide the input and analysis process. |
| Neither the vendors nor we understand how to layout a good manufacturing cell. | 1. Tools for cellular design are required<br>2. Background is required in cellular design |
| We need to analyze the flow between lines. We have to figure out the amount of inventory required. | Tools are required to analyze flow |
| I need evaluation in a couple of hours | Tools should provide analysis results within a day |
| Simulation is used for a close call or uncertain situation | General analysis does not require detailed analysis in design |
| After the line was installed, we found out the vendor's simulation was very inaccurate. It pointed to the wrong bottleneck. | Visteon engineers must be able to analyze and validate results. |

A statement-needs analysis is performed in Table 11. The purpose of this analysis was twofold: first, to understand what engineers require in a tool for it to be useful, and second, to verify the analyses required do not include data different from that of the Operations Engineering group's list. The needs from Table 11 are mostly considerations for the user interface design, while the Operations Engineering list defines the requirements the toolset should include.

In summary, the Operations Engineering requirements define the analysis requirements. The manufacturing engineers' information is used to define in what environment the tools are to be used, the requirements of the interface, and the types of analysis they require.

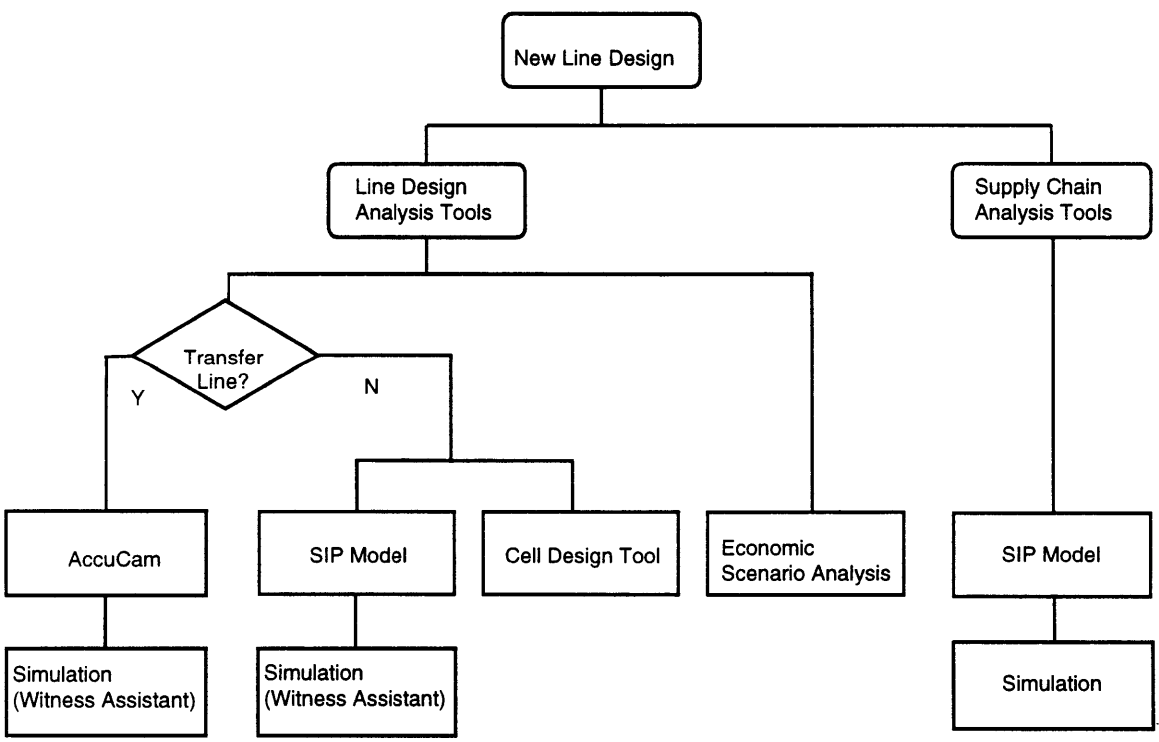
## 5.3. Recommended tools and applications

This section describes the proposed set of design tools, where each is applied, and the requirements for use. The section begins with an overview of the toolset, and then looks at each tool individually. Each tool is described in terms of use, inputs, outputs, and the theory behind the analysis tools.

### 5.3.1. Overview

Figure 12 shows the overall proposed toolset for manufacturing engineers

**Figure 12: Uses of Analysis Tools**



This figure shows the different tools for use in developing manufacturing lines. Simulation is still included, particularly through the use of *Witness Assistant.* The other, new tools include the SIP model, a Cell Design tool, economic simulations using *Crystal Ball,* as well as traditional simulation for the analysis of complex supply chains.

Table 12 shows how the proposed tools relate to the requirements defined by traditional Operations Engineering projects. The Cell Design and Economic Scenario Analysis tools resulted from needs seen by engineers, and are not included in the table.

**Table 12: Requirements / Analysis Tool Relationships**

| Operations Engineering Requirements | Proposed Analysis Tool |
|---|---|
| Capacity Analysis | AccuCAM, Witness Assistant |
| Buffer Sizing | AccuCAM, Witness Assistant, SIP |
| Reliability Analysis | AccuCAM |
| Material Flow | Witness Assistant, SIP |
| Scheduling Rules | Witness Assistant, SIP |

### 5.3.2. AccuCAM

***Use:*** As previously described, *AccuCAM* is a transfer line analysis tool that runs in *Excel.* Within the framework provided by the design methodology, *AccuCAM* would be used to analyze the throughput, capacity, and buffer requirements of a proposed line design.

***Inputs:*** To run an *AccuCAM* analysis, the engineer must have a list of basic inputs for line analysis. These include:

- Hours of operation per year
- Percentage of time used for setup
- Product to be manufactured
- Volumes for each product
- Operations required on the line, for each product
- Expected buffer size after each operation
- Number of machines for each operation
- Percentage down time for each operation
- Mean time to repair (MTTR) for each operation
- Scrap rates for each operation

***Outputs:*** The program provides throughput information for each product, the system load, and a bottleneck analysis for each product. The throughput analysis includes the expected rates of production for the proposed system, a system with infinite buffers, and a system with no buffers between stations. The purpose of the three throughput results is to provide intuition as to where improvement may be found by adding buffer capacity. For example, if a proposed line has a throughput very close to a zero buffer system, the engineer may be able to improve it by adding buffer capacity.

The system load measure provides the traditional capacity analysis commonly used in line design. The difference with *AccuCAM* is the load includes the variability factors from the queuing effects in the line. As such, it allows comparison with the traditional capacity analysis, which is the result given from the infinite buffer calculation.

Finally, the bottleneck analysis is calculated to provide the engineer with a target for capacity improvement efforts. While the intent may seem obvious, this feature is one which simulation and other analysis tools do not provide. Directing the engineer to improvement opportunities is an important feature of a design tool.

***Suggested Improvements:*** *AccuCAM* could become a more useful design tool by meeting more of the manufacturing engineer's needs. These revisions do not require changes to the core engine of the program, but to the application and presentation of the information. The changes are described below:

*Change the percentage down input to Mean Time Between Failures (MTBF).* While percentage down, MTBF, and MTTR are all related by a simple mathematical equation, most engineers, equipment vendors, and plants record data and think in terms of MTTR and MTBF. A second reason for this change is to force the manufacturing engineer to think about the validity of the numbers entered, and not the overall calculation. One of the points repeatedly mentioned in interviews was the need to understand vendor supplied reliability calculations. This stems from a number of factors, including a lack of history in operating the equipment, not controlling the maintenance of the machinery, and ambiguity over what is considered downtime.

*Provide an OEE calculation for the system.* An additional output should be an overall system OEE calculation. System OEE is one of the FPS measurables and is a commonly required value in system specifications. Providing the OEE implied by building up an entire system from individual operations would give a credible overall number and realistic expectations for results at run-off and launch.

*Request setup time and number of changeovers rather than setup percentage.* Vendors and Visteon engineers specify equipment in terms of a maximum setup time rather than the percentage of time a line is in setup. With the time required, the engineer is forced to make assumptions and calculations on the operating pattern used and the ability of the plant to run to that schedule. The result is more emphasis on how the line will be managed rather than just a setup assumption.

*Iterate analysis to provide design direction:* A final modification includes having the program lead the engineer to design improvements. Since the program runs very rapidly, it should be able to vary certain factors to calculate sensitivity. For example, the engineer may want to know the effects of improving MTBF, and the program could run iterations over a range of values to provide results. These calculations would be important on MTBF, MTTR, and buffer size, where the throughput relationship is not linear with value.

### 5.3.3. Witness Assistant

*Uses: Witness Assistant* provides two types of simulation analyses within the proposed framework. First, it can analyze lines more complex than those studied with *AccuCAM.* These include cross-loaded machines or lines, complex routings, and complex bills of material. Second, the program can be used to analyze the flow of material through different processes in a plant, including the inventory and scheduling policy, shift patterns, and product allocations. The tool is designed to result in an analysis of flow through a plant, and not the detailed design of an individual line.

***Inputs:*** Since *Witness Assistant* runs a discrete event simulation, the information required is more complex than with *AccuCAM*, but not to the level required in very detailed simulations. The inputs required include:

- Product Names
- Reorder Points
- Buffer Capacities
- Shift patterns
- Setup times
- Scrap Rates
- Product Families
- Product Routing
- Demand
- Machine Reliability
- Cycle Times
- Lot sizes

***Outputs:*** The program provides a variety of output in a spreadsheet format. The results are more detailed than with *AccuCAM*, as would be expected from simulation. The model provides data in a spreadsheet and graphical form on several parameters, including WIP vs. Time, demand vs. Time, shipments vs. Time, backlog vs. Time, scrap, flow time, and utilization results.

***Improvements:*** To make *Witness Assistant* more useful for engineers, minor modifications should be made to the output sheets. Primarily, these involve using the data provided to calculate FPS measurables for the proposed system. Focusing the engineer's attention on the FPS measurables provides a means of avoiding optimizing sub-systems without working to design an efficient overall system.

Using the existing outputs, the first time through, dock-to-dock, build to schedule, and system OEE measurables can all be calculated. These measurables provide a basis for comparison of different line designs, and also relate the design into the terms on which plant management is measured.

### 5.3.4. Strategic Inventory Placement (SIP) Model

The SIP model is a program developed at MIT by Professor Stephen Graves and Sean Willems as part of the MIT Leaders for Manufacturing program. It is designed to determine optimum stocking policies in distribution and assembly networks.

*Uses:* The SIP tool fits two analysis needs for manufacturing engineers and the Operations Engineering group. First, in analyzing supply chains, the tool supplies optimal policies for the supply network. The Operations Engineering section has recently completed several projects answering this type of question, and the SIP tool fits their requirements well. It can also be used as an initial analysis prior to running a more detailed simulation to provide insight into what policies to study in the model.

A second use of the tool is more closely related to the process of line design. This involves inventory and scheduling policies within the plant. Many Visteon processes combine basic manufacturing operations with separate assembly and test lines, all of which must be coordinated for efficient operation. In developing new lines, manufacturing engineers must consider the policies that will manage the flow through the plant.

***Inputs:*** The inputs to the SIP tool are:

- Product demand
- Cost of capital
- Service levels for each stage
- Cost added at each stage of the process
- Lead times for each stage of the process

***Outputs:*** The SIP tool provides the required inventory levels to meet the service requirements entered into the program. To the manufacturing engineer designing a new process, this provides an overview into the plant requirements to operate the new system without having to simulate an entire plant's operations.

The optimization routine then calculates the optimum stocking policy to minimize costs for the proposed system. This shows the engineer or analyst when opportunities exist to reduce the total cost of the system and what effects occur on service times and storage space.

### 5.3.5. Cell Design Tool

*Uses:* With the market driving Visteon away from high volume, low variation products, manufacturing cells are being evaluated for use in many new processes. An observed need in this area is the ability to design an efficient cell for both machine and operator assignment.

The design of a cell involves two aspects, machine location and operator loop definition. Machine location is placing machines spatially for the process to be carried out, most often in a U shaped layout. Operator loop design requires specifying which machines each operator tends, and in what order. The concept of the cell is to pace production by the slowest operator loop time, rather than by machine capacity. This is derived from the autonomation concept from the Toyota Production System, which values operators as a greater investment than equipment (Shingo, 1989).

***Applied Theory:*** The method for developing the tool is based on a paper by Graves and Holmes Redfield (1988), which solves an equipment selection and task assignment problem. The method presented in the paper selects equipment and assigns tasks based on a set of candidate workstations and the operation precedence structure. A feasible set of workstations is determined, and an integer programming problem is solved for the optimum system.

For the cell design tool, a similar structure is proposed where the solution involves selecting both the appropriate machines and order, and the operator loops. Defining the operator loops is a similar selection process where all the cell's operations must be accounted for by a number of operators in the minimum amount of time.

***Inputs:*** The model requires, for each machine, the operation time, the tool required, and the tool cost for each machine that must be chosen from. The model must also include any precedence requirements for the individual operations. To assign operator loops, the operator processing time must be known for each operation, including travel times between stations.

***Outputs:*** The output of the tool is the optimum machine order and operator loops. These assignments must be compared with existing conditions within the plant to verify the acceptability of the design. Acceptance of operators, ability to manage the cell, and information flows through the plant are important aspects of the design this tool does not address.

### 5.3.6. Economic Scenario Simulation

One of the major issues manufacturing engineers face in determining what type of line to build is valuing flexibility. The current design process assumes that the demand forecasts from the business planning office are the requirements the line will face. The result is often processes that do not perform well under volume changes over the life of the product. This section proposes a simulation tool to allow profitability analysis of line proposals under various demand scenarios.

**Uses:** When design concepts are received, manufacturing engineers often have a good estimate of the material, overhead, and labor costs to operate the process under the expected shift pattern. However, design evaluation under varying demand is cumbersome since a specific tool does not exist. The expected use of this tool would apply to both the early and concept evaluation phases of the design.

***Overview:*** The simulation tool is easily implemented in an *Excel* template to run with the *Crystal Ball* add-in. This would permit a spreadsheet format that engineers are familiar with, and the analysis of the line performance under varying demand scenarios.

Advantages of the format include allowing the use of the plant's accepted financial format, the familiarity with *Excel* as a standard software package, and the ease of developing the tool. Since the application involves the use of existing software packages, the Operations Engineering section would not have to commit significant resources to development.

***Inputs:*** For any set of proposed design concepts, the engineer would need a set of standard inputs to the model. Important factors are the ones that change with different processes and volumes, which include capital cost, labor, materials, non-variable overhead, variable overhead, scrap, taxes, profit sharing and other accounts. For most analyses, the trade off is between capital expenditure and labor costs under the various scenarios.

***Outputs:*** The output from the tool should be used at several levels. First, a Net Present Value calculation should be made to determine the overall range of values for a line. This provides the decision maker with the value and risks inherent in a new process. Results also should be given to show the effects of volume fluctuation and the sensitivity of the NPV on various inputs. The intent is understanding the costs and risks being accepted with a specific design.

## 5.4. Summary

This section proposed a set of analysis tools for manufacturing engineers and others involved with the design of new processes. The tools are more tactical than the traditional simulation and other analysis packages and are intended to be easier and faster to use. A needs analysis for manufacturing engineers was presented in an effort to define tools that combine the designer's requirements with the expertise of the Operations Engineering group.

# 6. Implementation Considerations and Conclusions

This chapter reviews methodology implementation issues and the conclusions from this thesis. Implementing the proposed methodology includes defining applications and support, as well as planning the development of new analysis tools. The chapter ends with four conclusions regarding the manufacturing development process.

## 6.1. Implementation

### 6.1.1. Methodology Implementation

Implementation of the design methodology requires three steps, including targeting an initial application, refining the process and obtaining acceptance, and creating training and documentation packages. Implementation will involve a significant amount of adaptation due to the diverse set of organizations and processes within Visteon.

***Initial Application:*** The first step in implementation is to target and develop an initial application using the methodology. The first use of the process needs to provide several benefits including a success story, a reference for improvement, and exposure within Visteon. The project need not be large, but must have enough scope to have a significant impact. The design team must be able to develop the line with management and analytical support since the proposed methodology requires new resources in the design process.

Two success factors in the implementation are the support of manufacturing engineers and that the designers have expectations different from previous lines. If the initial application is expected to be similar to an existing line, there is little value in utilizing the design methodology and the application will have minimal impact on the organization.

Selecting an appropriate initial application has a large effect on success: it provides exposure to people who benefit from the methodology, demonstrates an impact on the using plant, and gains acceptance by the users. To gain these benefits the application should have sufficient management attention and support, be wide enough in scope to benefit from the overall system design, and have enough freedom in strategy to implement improvements where they are possible.

***Refine and Define Uses:*** The initial application should be followed with reflection and improvement to the process. To lead this process, a champion for methodology development should be identified to direct and support the process. The methodology will require refinement, as well as the approach and training used. Particularly in the area of system architecture design, manufacturing engineers have widely disparate skills that must be addressed in the approach.

A second area for development is the role the Operations Engineering section expects to take. The group can add value in two roles, first as a resource for analysis and model building, and second as a facilitator of the process. The first role requires only developing familiarity with the analysis tools since the role aligns well with the section's current projects. Facilitation requires a different skill set, however. The section needs to evaluate how they wish to interact with various manufacturing engineering groups, what role to play, and how to approach potential customers. These roles need to be developed by using the methodology and understanding the customer base.

***Training and Documentation:*** To gain acceptance the methodology will require training and documentation. To meet the needs of the manufacturing engineers the training must be easy to access and learn. The materials are most easily maintained and accessed from the Operation Engineering section's intranet web site, which provides access and control over master documents. As experience with the process accumulates, additional information could include analysis guidelines for different types of processes, access to other successful designs, and records of ways to improve the methodology.

### 6.1.2. Analysis Tool Development and Support

In developing a suite of analysis tools to support manufacturing process design, the Operations Engineering section must consider three issues. First, how should the tools be developed or acquired? Second, how should the distribution and application of the programs be accomplished? Finally, the group needs to consider how to maintain, service, and support the tools and their application.

***Development:*** Given the strong demand for analysis tools meeting the needs of manufacturing engineers, the Operations Engineering group needs a rapid initial rollout. Of the proposed tools, *Witness Assistant, AccuCAM,* and the *SIP* models are all ready to use, or can be with very little modification. These programs should be the first targets of the development efforts. Of the three programs, only *AccuCAM* has a current developer within the section. A champion must be identified for the other two tools.

After deciding on a champion, the section can begin work on an economic simulation tool. First the software must be identified. The software must have an easy to learn interface, be adaptable to the various computers engineers use, and be modifiable. Second, the section must identify the level of detail to put in the analysis. This may vary among different projects, as different plants may use different accounting statements. However, the basic idea remains the same.

An additional area for Operations Engineering section development is a simulation package to aid scheduling analysis. The *Witness* program does not provide a straightforward method of programming scheduling logic, which is required in many projects. This is a relatively low risk area for the Operations Engineering section since the group maintains experts in simulation. Since the primary user is still an analyst, and not manufacturing engineers, this tool fits well within the sections current expertise.

***Implementation:*** The implementation of the tools involves distribution, instruction, and awareness. Distribution is the easiest issue as the section already has some software programs available over the Visteon intranet. This method would fit this toolset also. Instructions and documentation can also be distributed over the intranet and be included in the same download.

Awareness is a different issue. Visteon is a large, geographically diverse enterprise with a variety of organizational structures. Contacting the various manufacturing engineers can be accomplished via e-mail, which provides a medium. The issue the Operations Engineering group must contend with is timing.

Since any individual manufacturing engineer will work on a new project less than once a year, a single e-mail will not develop a high level of awareness or usage. Thus, the group needs a trigger to start inquires when an engineer begins a project. This can be accomplished by targeting departments with new projects at regular intervals, which increases the exposure level of the Operations Engineering group.

***Service and support:*** This aspect of the tools set is the easiest to accomplish. The documentation that accompanies each tool must be easy to understand and outline the usage and limitations of the tool. Also, the section can provide means of contacting a resource person within the section. This may include a help e-mail address and phone number or other means of contact. Given the Operational Engineering position in the organizational chart of Visteon, they are ideally suited for the support role.

## 6.2. Conclusions

***There is a need for a systematic process design methodology.*** To ensure the consistent development of efficient new manufacturing lines, a design methodology offers significant benefits to a manufacturing organization. Both as a checklist and a means of developing efficient lines, a defined process provides direction and ensures completion of design steps while leaving room for the engineer to design effective processes.

***Different and new tools are required for manufacturing process design.*** The traditional analysis tools that are currently used are suited for the analysis of existing and completed designs, but do not fit the needs of a manufacturing engineer in the design process. The engineers require easier to learn and use tools that provide rapid results, as contrasted with existing, detailed tools that were designed for process improvement.

***The expectations of system integrators must reflect the desired process.*** Traditional system integrators for a product line cannot necessarily provide expertise in a new style of line, as was evidenced in the cell implementation example. Even if an integrator can add value in the new line design, they likely cannot optimize the line for a plant's management, operators, and customers without input from the manufacturing engineer. The design of efficient processes requires that the customer, plant, operator, supply chain, and product systems be considered, which is information the supplier must obtain during the development process.

***The engineers must design the plant operations.*** To ensure efficient manufacturing systems, sub-systems should be designed to optimize the entire system. Engineering expertise is required to meet the needs of the various stakeholders in a new process, and must be reflected in the specifications and proposed designs.

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