Supply Chain Inventory Reduction Using Analytic and Simulation Techniques

by

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S.B., Electrical Engineering
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Submitted to the Sloan School of Management and the
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ABSTRACT

This thesis analyzes inventory levels in two supply chains of an automobile manufacturer. Both supply chains studied began from the manufacturing of an automotive sub-assembly and ended with the installing of that part onto an automobile at the assembly plant.

There were two main drivers of the thesis. One was to reduce inventory in the supply chain. The second was to recommend changes in the management system of the chain that would support such a reduction. The author expects the "system view" presented to provide a basic operating plan for plant management as they pursue inventory reduction goals.

The analysis method pursued in the thesis is of particular importance for automotive manufacturers and suppliers who must provide a specific sequence of complex parts to a customer. This thesis analyzes a few different inventory management schemes for such a system, including a tightly coupled Just-in-time (JIT) system called In-Line Vehicle Sequencing (ILVS). I present the constraints and requirements of such a system in detail. Mathematical and computer simulation models are used in conjunction with input from plant personnel in order to make final recommendations to plant management.

The two supply chains studied provide case studies which show how different system constraints affect inventory levels and the choice of an appropriate inventory management system. The two supply chains vary in terms of manufacturing complexity as well as final assembly line requirements By comparing and contrasting the supply chain requirements and the results from analyzing these two chains, the author hopes to provide a basis for future reduction needs for parts that have similar supply chain constraints, or whose supply chain has certain characteristics in common with the two studied. Furthermore, the author suggests methods to reduce the inventory levels in the two supply chains studied, which are hoped to be implemented within two years.

Thesis Supervisors:
Don Rosenfield, Sloan School of Management
Professor John R. Williams, Civil and Environmental Engineering
Zygmund Lipka, Ford Motor Company Supervisor

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Dedication

To my lovely wife, Sheila, who endured all of graduate school right beside me. Without her, graduate school would be more than lonely and more than I could handle.

To my parents, George and Jeraldine, without whom I would have never made it through my undergraduate years, much less graduate school. And to my sisters, Nanine and Risa, who have encouraged me through my college years.

I am sure they will **all** find my thesis **enjoyable reading**!

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1. Introduction

1.1. Background and Motivation

Currently when supplying automobile assembly plants with parts (interior door trim panels, plastic bumper covers, etc.), the Utica Trim Plant, a plant owned by Ford Motor Company, sends the parts to a warehouse which stores and sequences the parts before shipping them to the final automobile assembly plant. Millions of dollars of inventory pass through these warehouses every year. The motivation for this thesis is the substantial cost of carrying this inventory. This includes the cost of additional warehouse space,[1] the cost of personnel required to manage the warehouse, potential damage resulting from double handling, added transportation costs, the cost of additional material handling equipment (forklifts, storage racks, etc.), the economic carrying cost of inventory, and the cost of inventory obsolescence.

The goal of the thesis is twofold.

1. To help reduce this cost by cutting inventory without reducing throughput or increasing manufacturing cost, and
2. To recommend changes in the management of the supply chain that will help achieve such a reduction in inventory.

It is important to note that this thesis does not claim to represent the current state of production and management at the Utica Trim Plant of Ford Motor Company. The thesis is a result of a study done between June and December 1994. The plant environment is a dynamic one, and changes were being made at that time and will continue to made, as should be the case in all manufacturing firms that expect to remain competitive.

The analysis and results presented attempt to predict the steady state conditions in the plant for the 1995 model year. This state lies between the launch phase of production and the model changeover phase for the next model year. Unfortunately, a great deal of

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[1] Warehouse space is of particular importance. At the time of this thesis, Utica was engaged in a strategy that planned on introducing more work in a plant that many already felt was crowded.

the data collected was during model year changeovers. Therefore, many assumptions were made which will be explained later.

Before continuing, I think it is also important to clarify a few terms which I will use. These terms follow:

fascia: An automotive sub-assembly that is essentially the plastic front and rear bumper cover on a car.

interior door trim panel: An automotive sub-assembly that is on the interior side of a car door. It is the section of the door that the passenger and driver see and have physical contact with while inside the vehicle.

stock keeping unit (s.k.u.): A stock keeping unit is an item of stock that is completely specified as to function, style, size, color, and location on an automobile. For example, two interior door panels that are the same except for their color constitute two unique s.k.u.'s (Silver & Peterson, 1985, p. 12). An s.k.u. will also be referenced as an *end item* or *finished good* for Utica.

part: For the purposes of this thesis, a part will represent all s.k.u.'s having a similar function and placement on an automobile. Differently colored Ford Probe interior door panels constitute different s.k.u.'s but are referenced as the same part. Similarly, Lincoln Mark VIII fascias of the same color, but one a front fascia and the other a rear fascia, are referenced as two different parts. Put simply, the part definition above excludes color complexity.

safety stock: Safety stock is the inventory necessary to provide a certain service level in order to overcome the uncertainties in a production environment. I will borrow the definition of safety stock being "the inventory that is needed because the manufacturing environment is both uncertain and capacitated" (Graves, 1988, p. 67). Although one would hope for a service level of 100%, theoretically this would require an infinite amount of inventory. Often, from a practical standpoint, a service level of 98% is typical.

lead time: The lead time is typically defined as the time from when a s.k.u. is ordered to when that order is filled. Since the supply chain is limited in this case, that definition has been modified. The lead time in this thesis is the time from a s.k.u. being initially placed in the production queue at Utica until that s.k.u. is delivered to the final assembly line and placed on an automobile.

replenishment lead time: Replenishment lead time is similar to lead time except that the time is given for a certain inventory stocking point. Replenishment lead time is the time from a s.k.u. being initially placed in the production queue at Utica until that s.k.u. arrives at a certain inventory stocking point.

1.2. Supply Chain Studied

The supply chain studied is diagrammed below in Figure 1.2-1. The Utica Trim Plant is represented by the subassembly part production box.

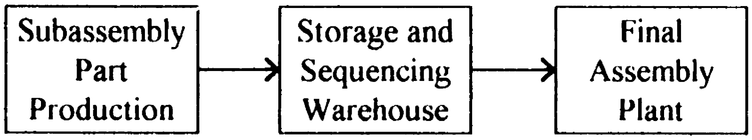

Figure 1.2-1: Supply Chain Diagram

This section of the supply chain was studied for several reasons. First, management felt that the warehouses were holding too much inventory. Second, to limit the scope of trying to solve this inventory concern, the immediate processes upstream and downstream of the warehouse were investigated. Raw material inventory supplying the subassembly part production plant was left out of the study and assumed to be readily available. This assumption was made due to a management perception that raw material inventory was not a major concern, and the fact that many of the raw materials could be classified as commodities.[2] Furthermore, it was a common assumption that raw materials were supplied as needed when modeling plant processes with computer simulation. In the supply chain, I focus mainly on finished goods inventory levels and have a partial focus on the work-in-process (WIP) inventory within subassembly part production.

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[2] Plastic pellets, rolls of vinyl, barrels of adhesive, sheets of carpet, and staples are all examples of raw materials used by the subassembly production plant.

1.3. *The Assembly Plant Customer*

The supply chain described above shows that the customer of the Utica Trim Plant is the automobile final assembly plant. This customer has a sequencing requirement that was a specific focus of this thesis.

The sequencing requirement can be best understood by a brief look at the way an assembly plant operates. The plant can be divided into three sections. Figure 1.3-1 shows these sections with the basic flow of parts between them.

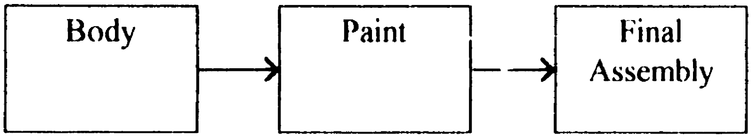

Figure 1.3-1: Main Sections of a Final Assembly Plant

Each section of the assembly plant tries to optimize production in entirely different ways.

Body: Body is where the metal framework of the car is welded and fastened together. Batch production of the unique body frameworks is the desired production system is this section.

Paint: The paint section is where the automobile frame is painted with the desired color. In order for the system to minimize paint flushes[3] and improve yield[4], unique color batches are produced.

Final Assembly: Final assembly is where the body is joined with the chassis and power train. It is also where all the options and subassemblies of the automobile are installed onto a car on an assembly line. This section assembles cars using the balanced-line approach. For example, two door vehicles are mixed with four door vehicles in order to balance the load on the door installation section of the line.[5]

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[3] Flushes occur when the color is changed. Pipes and hoses are flushed clean with a chemical so that the next color will not mix with the previous color.

[4] Plant management has shown that the paint yield improves with larger batch sizes.

[5] This balancing also relieves suppliers from a surge of workload. A particular supplier can stick to a uniform cycle time throughout a production period without creating the waste of inventory. For a discussion of this *heijunka* principle see Mishina, "Toyota Motor Manufacturing, U.S.A."

Given these drivers, coupled with the fact that the yields of typical body paint system are difficult to predict, forecasting the actual sequence of cars moving down the assembly line much in advance is very difficult.

In terms of supplying the assembly plant, shortages cause cars to go off-line at the assembly plant, and in some instances can cause the entire final assembly line to shut down. Such a mistake can cause significant monetary loss. On the otherhand, small amounts excess inventory is "less costly" than one shortage and such considerations can lead to high inventory levels.

1.4. Thesis Focus

1.4.1. Inventory Decisions and Factors Considered

This thesis focuses on two important inventory decisions for the supply chain shown in Figure 1.2-1. They are as follows:

1. What is the level of inventory that should be maintained at each point in the supply chain?
2. Where in the chain should the parts be sequenced before installation onto the automobile?

There are several factors which affect the decisions to be made. These include:

Uncertainty: Stated simply, inventory levels are a direct result of uncertainty. This uncertainty exists in demand forecasts, production uncertainties (scrap, yield, downtime, etc.), and transportation uncertainty. The uncertainty can exist in management as well. A line supervisor may perceive an uncertainty and protect from a shortage with inventory. If forecasts were perfect, production was predictable, transportation was always on time, management knew exactly what was going on in production at all times, and there was enough capacity, inventory levels should be zero. To achieve this, all the system would have to do is use a Material Requirements Planning (MRP) system to transmit demand back to all supplying levels and everyone would be able to supply everything perfectly and on time. Unfortunately, the world is not that easy.

Number of different s.k.u.'s required by the final assembly line (s.k.u. complexity): This particular factor affects the choice of where the part should be sequenced. For example, if the same part is to be used on every car that comes down the assembly line, it is reasonable to assume that the part will be most easily sequenced very close to the assembly line. Consider a screw which fits on every car model on a line. The worker near the line could just pick a screw out of a box. On the other hand, consider different cars coming down the line which require fifty different door panels based on color complexity, power mirror options, and power lock options. It is not reasonable to expect fifty different boxes of door panels, a part which is significantly larger than a screw, to be placed near the assembly line and have the line worker pick out the necessary panel when the car comes by.

Part size and space availability: Even if the part is not complex, the size of the part may limit the number of parts that can be located next to the assembly line.[6] Obviously, if there is a space limitation near an assembly line station this limits the number of parts which can be stored there. These characteristics affect not only the storage of parts at the assembly line, but also inventory storage throughout the supply chain. If the space is not available, more inventory cannot be held.

Time between the correct sequence broadcast until the s.k.u. is installed onto the automobile (broadcast lead time): If Utica knew the correct sequence a day in advance, and had the capacity to fulfill that demand, it is not unreasonable to expect Utica to supply parts in sequence to the assembly plant. On the other hand, as this time decreases, more finished goods inventory is needed to "pick the sequence from" so that the customer will be serviced on time.

Transportation constraints: Transportation time between a supplier and customer affects inventory levels. Typically, the longer the transportation lead time, the higher the finished goods inventory. This is due to the fact that each shipment must carry at least the amount of inventory for the transportation time plus a production period.

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[6] Generally speaking, there is a limited amount of space available at each station next to an automobile assembly line. Inventory is typically stored at intermediate warehouses and/or at a warehouse in the final assembly plant and then moved to the line with material handling equipment.

Production constraints: Scrap, downtime, machine set-ups, repair and rework, cycle times, and capacity can all affect inventory placement and levels.

Costs: Costs of the production system and the corresponding management system also affect the decisions. As my supervisor said, "Anyone can reduce inventory if you let them spend as much money as they want. They could simply buy more machines and never worry about utilization."

Management issues: Finally, management issues are important. The culture of an organization can encourage inventory as well as discourage it. For example, a piece-rate pay scale can often give workers the incentive to produce more parts than needed.

Although each of these factors is important, I concentrate on a select few. Uncertainty is a major factor considered, especially forecasting uncertainty which directly leads to safety stock calculations. Production uncertainty and constraints are also considered. I considered s.k.u. complexity as well as broadcast lead time. Finally, constant transportation lead time (without uncertainty) was considered.

Only a few recommendations focused on management issues. The recommendations try to encourage inventory reduction. A main focus involved costs, but during the limited internship it was impossible to gather all of the relevant costing information. Instead, possible inventory savings due to a reduction in inventory were calculated. Potential costs are named but not quantified, but the inventory savings value provides a baseline to compare with actual cost figures. The focus on part size and space availability is limited since both supply chains contain large parts with space at a premium.

1.4.2. Production and Management System

"What type of management and production system will support the decisions made for questions one and two above?" is the final question contemplated. The main focus is on the general production system and basic operating plan suggestions, with a few comments on the management system structure.

A partial focus of this thesis deals specifically with a production system called In-Line Vehicle Sequencing (ILVS). In Ford jargon, this term represents a tightly coupled Just-in-time (JIT) system whose goal is to broadcast a 98% accurate sequence to the suppliers five days in advance of the final assembly of the automobile. Instead of a 5-day fixed sequence, the current system broadcasts the sequence as it develops when automobiles are pulled out of the paint system (see figure 1.3-1).[7] These broadcasts are sent to the intermediate warehouse in figure 1.2-1, and the s.k.u.'s are pulled from inventory and shipped in sequence.

Due to the current inability of ILVS to consistently achieve its goal of 98% accuracy over a 5-day period, I do not limit my analysis to ILVS. Instead, I analyze JIT opportunities to pull the sequence earlier in the supply chain (which do not require the success of ILVS) in addition to identifying specific benefits that ILVS could provide if it is successful in its goal of a 98% accurate 5-day fixed assembly sequence.[8]

1.4.3. Explanation of Case Studies

To give a spectrum of examination, two different supply chains were studied. They were an interior door panel chain (ST44, or Ford Probe), and a fascia chain focusing mainly on the high end fascias.[9] The choice of the chains was such that they varied significantly in terms of the factors presented in Section 1.4.1 and in terms of JIT possibilities. By comparing and contrasting the supply chain requirements and the results from analyzing these two chains, I hope to provide a basis for future reduction needs for parts that have similar supply chain constraints, or whose supply chain has certain characteristics in common with the two studied. The similarities and differences in the two chains will become clear in the sections following chapter 1.

1.5. Literature Implications

Before continuing, I did some research in available literature on related topics. I summarize the results of that search in this section.

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[7] After paint and before final assembly, line balancing is done so that the sequence remains fixed (except for unexplained problems which cause cars to pulled off of the line and out of sequence).

[8] ILVS is simply a JIT conception that would allow suppliers a much greater lead time (5 days compared with hours) with a more accurate forecast of the assembly plant's demands.

[9] The high end fascias were for the luxury cars such as the Towncar, Continental, and Mark VIII.

1.5.1. Supply Chain Notes

With the supply chain studied, it seems that a base stock system is adequate to describe what goes on in the current production system at Utica, except for the batch production that occurs. In such systems, the inventory process begins with a base level of inventory called the base stock. Whenever a customer order for r units is given, an inventory replenishment order is given for r units and filled after a lead time (the replenishment lead time, L). If demand cannot be satisfied from inventory, customers wait for the arrival of an s.k.u. (stock is backordered, not lost). Such a description seems adequate for the supply chain studied and is the method of analysis used for this thesis.[10]

In the supply chain studied, one can either analyze the specific costs of the production system to determine production levels and scheduling frequency (such as the cost of overstocking versus the cost of understocking). In this supply chain, a shortage causes a car to go off-line at an assembly plant and is thus very expensive. The cost of incremental overstocking is much less. It is very difficult to quantify these costs exactly, especially when qualitative factors are considered (such as supplier punishment).

Thus it is important to describe the service level for the system (Magee, 1985, p.82). The type of service chosen for analysis was the probability of not stocking out in the lead time. One reason for the choice is that it makes sense in this production environment. Management wants the probability that a stockout will occur in any period (which is a day in the analysis sections) to be very small. This Type 1 level of service is useful when a shortage has the same consequence independent of the time or the amount of the shortage (Nahmias, 1993, p. 261-262). If an assembly plant experiences a shortage of Utica s.k.u.'s, a car will most likely be put off-line. If there are multiple shortages more cars will be pulled off-line, so the service type is not entirely applicable.

However, considering that a production lot in the analysis sections is at least a day, a 98% Type 1 service level implies that, on average, a stockout of one or more units would occur in only 1 out of 50 days, or less. Type 2 service is the percent of demand met from stock. Calculations using this type of service are more complex, although this type of

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[10] For further information, see <u>Operations Research in Production and Inventory Control</u>, p. 50

service might be more applicable. To solve the dilemma, I calculated approximate safety stock levels for Mark VIII fascias using both methods. Although the results showed different results for the same numerical service level (98%), the units of safety stock calculated in Type 1 service always succeeded in providing a higher level of Type 2 service (greater than 98%). Thus, Type 1 service chosen as a suitable conservative model to use.

In terms of the supply chain, the literature also provided some insights into inventory locations for the supply chain, shown again below.

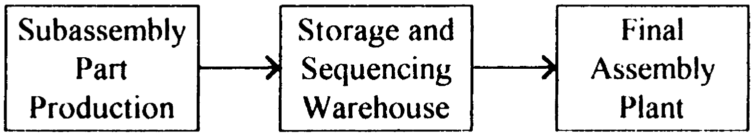

Figure 1.5-1: Redrawing of the Supply Chain Studied

In a base stock pull system production environment, the sections of the supply chain above are coupled. This simply means that the assembly plant demand depends upon the production process of the supplying plant. The following information about inventory location seemed particularly beneficial for this system:

- Since the stages are linear, and the warehouse supplies only one assembly plant, the warehouse should store safety stock, stock which protects for transportation uncertainty from Utica, stock due from batch production, and stock resulting from a particular inventory control policy (for example, trying to produce one day ahead of demand).
- Utica could store some stock to protect for unexpected production uncertainty (downtime and scrap), but should mainly function as a staging area before parts are shipped to the sequencing warehouse.
- Likewise, the assembly plant could store for assembly production uncertainty. The assembly plant should also protect for transportation uncertainty from the warehouse.[11]

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[11] For further information on multi-stage distribution choices, see Modern Logistics Management, pp. 98-100.

- It should also be noted that there could be stock stored for *ultimate demand*[12] uncertainty at any of the locations in the supply chain studied. This thesis does not consider that case. Instead, I assume that stock outside of this supply chain (for example, at the dealerships) would account for such uncertainty.

1.5.2. Current Automobile Manufacturing Trends

In United States automobile manufacturing there is a major focus on trying to make operations more lean. Japanese success stories in lean production and in concepts such has JIT and Kanban have fueled much of this attention. Lean production includes principles such as teamwork, communication, and continuous improvement, but relates to this thesis with its emphasis on the efficient use of resources and the elimination of waste (Womack, 1991). "Inventory is but one of the many nonvalue-added activities (others include rework, excessive material handling, and set-ups) that create waste in an operation. An underlying principle of Japanese production systems is the elimination of such waste" (Klein, 1991, p. 25). The book, The Machine that Changed the World, points out the difference in attitudes of Toyota and a "typical United States auto maker." American auto manufacturers have "believed that extra space is necessary to work on vehicles needing repairs and to store the large inventories needed to ensure smooth production" (Womack, 1991, p. 79), while Toyota has driven toward a "lean system with as little slack as possible" (Womack, 1991, p. 103).

Pull systems from Japan, mainly JIT and Kanban, have gained considerable attention from the automobile industry. Kanban is a particular implementation of a pull system where the replenishment signals are given by cards which "control production schedules and hence over-all inventory levels" (Maruyama, 1982, p. 2).[13] The concept of JIT has gained much attention in automotive manufacturing. There are many popular

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[12] This refers to the demand of the ultimate consumer (the person who drives away with a car at a dealership).

[13] For a full-description of the Kanban system see The Kanban System and Its Characteristics by Takashi Maruyama.

books on the subject.[14] Obviously, Ford Motor Company is considering JIT by testing the concept of ILVS.

1.6. Summary of Conclusions

This thesis makes the general conclusions that are listed below. More specific results and conclusions are found in sections 2.3, 2.4, 3.3 and 3.4

- The current production systems for both Wixom fascias and ST44 door panels can provide equivalent customer service with less finished goods inventory. Furthermore, the analysis presented provides plant management with a method for further inventory reduction in other plant processes.
- Even in its testing phase, ILVS reduces forecast error for the Wixom fascias. This should directly result in lower safety stock levels and therefore reduce finished goods inventory levels.
- ILVS could provide an opportunity for a tightly coupled JIT system implementation for the ST44 door panel process, and door panel processes which have similar characteristics.
- There are ILVS and JIT opportunities for fascias, but the large size of the parts coupled with the lack of space available in the plant to store more inventory, makes implementation unfeasible at this point in time.
- There are similar JIT possibilities without ILVS for the ST44 door panel process, although other implementation factors affect feasibility at this point.
- Despite a lack of feasibility for some of the aspects covered by this thesis, the analysis presented provides plant management with a method for investigating ILVS and JIT opportunities for other processes within the plant.

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[14] Just a few of the books on the topic which I looked at were Zero Inventories, The Just-In-Time Breakthrough, and Attaining Manufacturing Excellence, all of which are referenced in the bibliography.

2. ST44 Door Panel Process

2.1. *Overview*

2.1.1. Manufacturing Process and Supply Chain

The ST44 Door Panel process during the 1995 model year is a simple assembly type operation. The detailed process diagram is displayed in appendix 6.1. Robots spray adhesive to molded plastic substrates.[1] The adhesive is applied so that a vinyl covering will stay attached to the exterior of the substrate. A pair of sprayed substrates, a substrate for the right door and a substrate for the left door, is placed in a vacuum-forming machine. This machine applies the vinyl upon the substrate. Excess vinyl is then trimmed. Outer vinyl edges are then folded and stapled onto the substrate to further secure the vinyl. The substrate is then placed into a press which punches holes for options such as a speaker grille, power window and mirror controls, etc. Options are installed onto the part, (such as the speaker grille, a weather strip, lock bezel, etc.) and held in place after a process called heatstaking.[2] Finally the part is inspected and repaired or scrapped as needed. For simplicity, the process diagram shows scrap produced only at two points in the line, after the vacuum-forming machine and at the end of the line. In reality, scrap can be generated at any process in the line. At the end of the line, the parts are packed in storage containers, stored briefly, and shipped to the CTI Warehouse which stores and sequences the s.k.u.'s before final shipment to the Ford and Mazda assembly plant (AAI).

The supply chain for the ST44 parts is

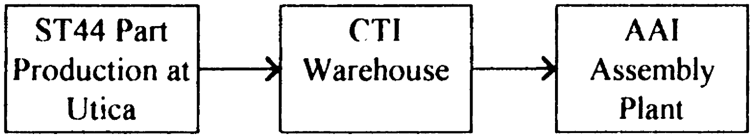

Figure 2.1-1: ST44 Supply Chain

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[1] Substrates are molded parts which are in the shape of an interior door panel. The rest of the assembly operation places different materials and items on this main molded body.

[2] Plastic options are applied to the substrate by pushing plastic stems through holes on the substrate. The heatstaking process melts the stems up to the back of the substrate, permanently fixing a plastic sub-part in place.

The CTI warehouse is located 1.5 hours from the Utica plant, and 25 minutes from the AAI assembly plant. AAI broadcasts the automobile assembly sequence to CTI. CTI then pulls the correct sequence from finished goods stock and ships the parts to AAI.

2.1.2. Current Production System

2.1.2.1. S.K.U. Complexity

The ST44 line produces the s.k.u.'s shown below in table 2.1-1. Note that there are 14 different right side s.k.u.'s and 20 different left side s.k.u.'s. This is because some of the right side s.k.u.'s fit on more than one car type (for example, s.k.u. R1 and L1 are for car type 1, while s.k.u. R1 and L2 are for car type 2).

Table 2.1-1: ST44 Door Panel Part Complexity

										4C	4C	4C	4C	4C	4C	4C		4C	4C		
SKU's	**SKU #**	**Car Type #**	**Raw Materials**	Adhesive(s)	Door Substrate: LH	Door Substrate: RH	Foam Pads	GT Insert Substrate: LH	GT Insert Substrate: RH	Lock Bezel	Map Pocket Assembly: LH	Map Pocket Assembly: RH	Pull Handle: LH	Pull Handle: RH	Speaker Grille: LH	Speaker Grille: RH	Staple	Tangle B/C	Vinyl	Weather Strip: LH	Weather Strip: RH
LX RH MW	R1	1,2	3C	X		X	X			X				X		X	X		X		X
LX LH PM MW	L1	1	3C	X	X		X			X			X		X		X		X	X	
LX LH MM MW	L2	2	3C	X	X		X			X			X		X		X		X	X	
LX RH PW MP	R2	3	3C	X		X	X			X		X		X		X	X		X		X
LX LH PM PW MP	L3	3	3C	X	X		X			X	X		X		X		X		X	X	
GT RH MW	R3	4,5	3C	X		X	X		X	X				X		X	X	X	X		X
GT LH MW	L4	4	3C	X	X		X	X		X			X		X		X	X	X	X	
GT LH MW PM	L5	5	3C	X	X		X	X		X			X		X		X	X	X	X	
GT RH PW MP	R4	6	3C	X		X	X		X	X		X		X		X	X	X	X		X
GT LH PW MP	L6	6	3C	X	X		X	X		X	X		X		X		X	X	X	X	
GT RH PM PW MP	R5	7	2C	X		X	X		X	X		X		X		X	X	X	X		X
GT LH PM PW MP	L7	7	2C	X	X		X	X		X	X		X		X		X	X	X	X	

KEY:
GT and LX are two types of Ford Probe automobiles
LH and RH stands for left hand and right hand sides respectively
MW and PW stands for manual window and power window respectively
MM and PM stands for manual mirror and power mirrow respectively
MP stands for map pocket
2C means a two color complexity of saddle and opal
3C means a three color complexity of ebony, willow, and opal
4C means a four color complexity of ebony, willow, opal, and saddle

For the purposes of this thesis, it is unimportant for the reader to understand the raw materials that make up each door panel. What is important is that the Ford Probe line has an s.k.u. complexity of 34.

2.1.2.2. Description of the Current Production System

The current production system is supposed to function as a base stock system.[3] What this means is that a base stock level, or inventory level, is maintained over each production period. Batch production in the ST44 process causes slight variations from this base stock level. Base stock consists of regular replenishment inventory plus safety stock. The production period used is a day. From observation and data, the production decision system for each s.k.u. can be described as follows:

1. The finished goods inventory levels of each s.k.u. are determined.
2. Demand is met from the replenishment finished goods inventory, and from the safety stock if production cannot replenish the finished goods inventory in time to service the customer.[4]
3. The amount of an s.k.u. to be produced is then determined from the amount of stock that needs to be replenished (if any), the amount of demand that cannot be met from inventory (if any), and the amount of future demand that can produced in order to smooth production for capacity and utilization constraints. Due to replenishment lead time, panel production attempted to stay one day ahead of production at AAI.
4. Finally, line schedulers adjust the amount to be produced based on scrap, downtime, and rework information.

Production of s.k.u.'s is generally done in batches of 24. The batch size is chosen in order to fill a shipping rack which stores exactly 24 door panels. Batch production is also done since the vinyl roll on the vacuum-forming machine must be changed when there

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[3] For further information on base stock see Graves, "Safety Stocks in Manufacturing Systems"; Kimball, "General principles of inventory control"; and Silver and Peterson, Decision Systems for Inventory Planning and Production Management.

[4] If there is not enough safety stock available, the production system expedites the s.k.u.'s needed by placing them at the front of the production queue, and shipping them out as soon as possible.

is a color change[5], and batch production allows stockmen enough time to supply the line with the parts necessary for the next batch. The line has enough capacity to meet daily demand, and the production decision is made daily using the procedure described above.

The aggregate inventory stocking point plan is described by the following table:[6]

Table 2.1-2: Current Finished Goods Inventory Plan[7]

Utica Finished Goods Inventory	
Contract Inventory at Utica Warehouse	2 days
Possible Inventory in Transit (deliver twice per shift)	4 hours
CTI Finished Goods Inventory	
Supply Lead Time Inventory at CTI warehouse	3 hours
Safety Stock at CTI	8 hours
Possible Inventory in Transit (delivery twice per shift)	4 hours
AAI Finished Goods Inventory	
AAI Warehouse Inventory	1.25 days
Maximum inventory allowed	5.5 days
Total planned inventory level	5 days
* A day of inventory is inventory for an 8 hour period	

During the course of my research, I was unable to obtain data which verified explicitly this operating plan. I was assured by AAI management that the plan was followed from CTI through AAI. At Utica, I was able to collect data which is summarized on the following chart:

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[5] Although such a change can be made with out any cycle time lost on the machine (zero set-up time), it would be unreasonable to think that the operator can make such changes constantly, which would be the case with a batch size of 1.

[6] This inventory plan is for the 1994 and 1995 model years.

[7] The contract inventory at Utica is what is specified in the joint venture agreement between Mazda and Ford.

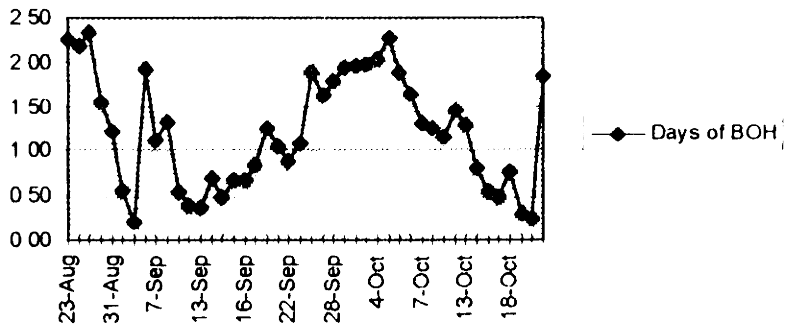

Figure 2.1-2: Days of BOH Inventory at the Utica Warehouse

The average BOH at Utica was 1.23 days, which is less than what is called for in the joint venture contract. Through inventory reduction efforts of its own, Utica felt that the same service level could maintained with less inventory. I used 1.23 days of inventory as a baseline to compare with inventory reduction calculations later.

The base stock level is maintained by the AAI assembly plant.[8] Mazda keeps track of the inventory levels (everywhere in the system except at the Utica warehouse and in-transit to CTI) and forecasts demand. Actual demand data is broadcast to the CTI warehouse as soon as cars come out of the paint line. The car type data is then translated into the interior door panel s.k.u. demand.[9] The forecast data is sent to Ford, and once again this data is translated into interior door panel s.k.u. forecasts.

2.1.2.3. Demand Forecasting Procedure

The demand forecasts are the production forecasts from the AAI assembly plant. These forecasts are for monthly periods, are made several months in advance, and updated every month. Such forecasts are mainly used for capacity planning and other long term planning. The first forecast used mainly for production planning (for reference, I will call this the Nth month forecast) is the forecast done for each month 11 weeks in advance.

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[8] The AutoAlliance, Inc. (AAI) assembly plant is a joint venture agreement between Mazda and Ford. The assembly plant produces the Mazda 626 and RX7 as well as the Ford Probe. The assembly plant is mainly operated by Mazda personnel, with Ford representatives.

[9] After automobile bodies have gone through paint, the sequence remains basically constant throughout the final assembly process. The sequence would vary based on unexpected line or supplier problems.

According to the AAI forecasting department, this forecast is "basically fixed until four weeks before production, at which point actual orders began to replace forecasts." At AAI the Nth month forecast is smoothed over a four week production period. For example, a forecast of 2000 cars for the month would translate into a production of 500 cars per week. These weekly forecasts are smoothed over the week, until finally, a daily forecast is obtained.[10]

The Nth month forecast is updated each week as actual orders are received. These adjusted weekly forecasts are given to Utica, and once again smoothed for daily production to obtain daily forecasts of car production at AAI. I collected these daily forecasts over a three month time horizon. Being smoothed, they are not true forecasts as desired, but the use of the forecasts are to predict actual car production. As such, they should provide very useful insight into the forecast uncertainty seen by the Utica production system.

2.2. Analysis

2.2.1. Supply Chain Models and Simulation

The model used to simulate production was the following:

- Production of an s.k.u. at time t is based on the one period ahead forecast from time t-1 (the forecast used here is that described in section 2.1.2.3). Production from time t was ready to be used in time t+1, or put simply, the replenishment lead time is a day.
- Expediting is allowed to occur for items that are "short to buck." These items are those which are not able to be filled from finished goods inventory, but are in the production plan for today (are demanded today). Obviously, such items are placed at the beginning of the production queue and shipped out as soon as possible.

With such a model, Utica is able to remain a day ahead of AAI production as desired, and expediting is allowed to occur.[11]

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[10] See Mishina p. 6, for a similar discussion of balancing daily production.

[11] As in similar production environments, such expediting occurs due mostly to unplanned uncertainties in production, transportation, and/or forecasts.

First, I analyzed the one day ahead forecast errors by the method described in appendix 6.3 with L=1. Due to the lack of data available for the 1995 model year, forecast errors for the ST44 door panel from the 1994 model year were used instead (see appendix 6.4). There were no known improvements to the forecasting procedures from year to year, so I assumed that when steady state is reached in the 1995 model year, the forecast error would have a similar data generating process.

The results of the analysis for 1994 parts were

Table 2.2-1: 1994 ST44 Safety Stock Calculation

Service Level (%)	k	Safety Stock (Days)
99.0	2.326	0.64
99.9	3.090	0.85

The safety stock is for finished goods inventory in the entire system. The total finished goods inventory in the system in 1994 averaged 3.855 days.[12] 3.855 days is total inventory, which includes safety stock inventory. Some of the difference can be accounted for by anticipated transportation uncertainty, production uncertainty, and inventory due to batch production (cycle stocks), but there is room for inventory reduction. I simulated the production system to further verify this possibility, but in order for the analysis to be useful I transformed the 1994 data into predicted 1995 steady state data.[13] I describe this transformation in detail in appendix 6.4.

Using the predicted forecast error for 1995, the following safety stock levels were obtained:

Table 2.2-2: 1995 ST44 Safety Stock Calculation

Service Level (%)	k	Safety Stock (Days)
99.0	2.326	0.72
99.9	3.090	0.95

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[12] Refer to Table 2.1-2 for CTI and AAI finished goods inventory and Figure 2.1-2 for Utica's finished goods inventory to calculate this number (1.23 days at Utica + 1 3/8 days at CTI + 1.25 days at AAI).

[13] Forecast data was not readily available to Utica employees. I was only able to obtain data for 3 months during the 1994 model year production.

Current average finished goods inventory is 3.855 days, which leaves about 3 days of inventory to account for production constraints (uncertainty, batching, etc.) and transportation uncertainty in the supply chain. There might be potential for inventory reduction, which is further tested using simulation. Table 2.2-2 assumes that each s.k.u. can be stored individually as safety stock. This is not entirely true since the s.k.u.'s are typically stored in racks of 24. Taking this into account, the safety stock level changes to 1.61 days for both service levels[14] and an effective service level that exceeds 99.999% for the majority of s.k.u.'s.

I ran a computer simulation of the supply chain under the assumptions and conditions described in section 7. These conditions included production constraints such as scrap, downtime, set-ups, s.k.u. batches of 24, and shipments to CTI in containers which held 24 units of one s.k.u. In order to achieve a high service level under batch production and other production constraints, average finished goods inventory is higher than the safety stock predictions. The simulation included an expediting feature to rush orders when a stock out was likely, and in all cases was able to maintain a 100% service level. The simulation resulted in an average system finished goods inventory of 2.3 days. The simulation did not account for transportation uncertainty, but in general it seems that the average system finished goods inventory level could be reduced by about a day.

With an average standard cost of $40 per panel, this amounts to a potential inventory economic savings (in terms of holding costs) of

Table 2.2-3: Potential ST44 Inventory Savings[15]

Potential Savings	Amount of Inventory Savings
Daily	$19.24
Weekly	$96.20
Yearly	$4569.60

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[14] This is more safety stock than needed since an s.k.u. with a calculated safety stock of 1 unit, is then determined to need a safety stock of 24. Multiples of 24 are the only options. Probabilistically, this amounts to an overestimation of about 0.6 days, but the storage method is more feasible.

[15] These values are calculated using the average standard cost of $40 per panel, an average demand of 400 cars per day (or 800 panels per day), a 5 day work week, 47.5 weeks in a year, and the inventory carrying cost shown in appendix 6.7.

Note that table 2.2-3 does not include the additional benefit of more warehouse space available due to 1 day less of inventory.

2.2.2. JIT Investigation

The first step in analyzing JIT possibilities is to determine where in the system s.k.u.'s can be sequenced according to the production sequence at the assembly plant. The possible options for the supply chain studied are anywhere between building in sequence at the beginning of the Utica production line, to sequencing the panels from batches at the assembly line.

Since these are large parts with an s.k.u. complexity of 34, it is infeasible to think that 34 part batches can be stored next to the assembly line where line workers could pick in sequence from those batches. Sequencing from the CTI warehouse is the current method and was analyzed in the previous section. Furthermore, sequencing at Utica after the s.k.u. is assembled, is very similar to sequencing a the CTI warehouse. The costs of space and labor to manage the sequencing would have to be weighed to determine which is more feasible. This calculation is not included in this thesis. That leaves building in sequence on the Utica line. This could occur at any point in the line, but was considered only after edgefolding for reasons that are explained below.

Figure 2.2-1: Process Location Where S.K.U. Complexity is Added

Complexity Additions	Number of Distinct Buffers Required	Process Sections
Left · Right	2	Door substrate raw materials through adhesive application
Ebony · Opal · Saddle · Willow	8	Vacuum forming through edgefold
GT or LX · MP · MW or PW · MM or PM	34	Punch through shipping

See Table 2.1-1 for a key to the codes used.

What figure 2.2-1 shows is that if buffers were kept from which the sequence was drawn, there would be 2 buffers after the door substrate raw materials, 2 buffers after adhesive application and before vacuum-forming, 8 distinct buffers after vacuum-forming, 8 distinct buffers after trimming, 8 distinct buffers after edgefolding, 34 distinct buffers after the punch presses, etc. (refer to appendix 6.1 for the entire process diagram).

A few process points can be eliminated before any empirical study is done. Storing parts after the adhesive is applied (i.e. after the oven) is not possible due to the state of the adhesive. The parts need to be immediately sent to the vacuum-forming machine. Storing after the vacuum-forming and before trimming, or after trimming and before edgefold, are possibilities which are eliminated due to the goal of pulling the sequence. Since the same number of distinct buffers would be maintained for all of these locations (8 in this case), the next thing to look at would be throughput time (the time from which the sequence is pulled until the time it is shipped). Therefore, if a position favoring 8 buffers were selected, one would want the storage location to be as late in the process as possible. Thus the final operations would be as few as possible and take less time. This implies that the storage location for a complexity of 8 would be after edgefold and before the punch operation.

Using the same argument, if 34 were chosen the buffer would be of finished goods inventory (similar to the current operation) and the choice left is the size and position of this buffer. As said previously, this type of system was analyzed in section 2.2.1.

This leaves the two choices

1. Building in sequence from the beginning of the line, or
2. Building in sequence after edgefold.

Although, building in sequence from the beginning of the line might be an option[16], I eliminated it due to lead time considerations. As shown in figure 2.2-2, there is a limited amount of lead time between the time the sequence is broadcast to the time when the

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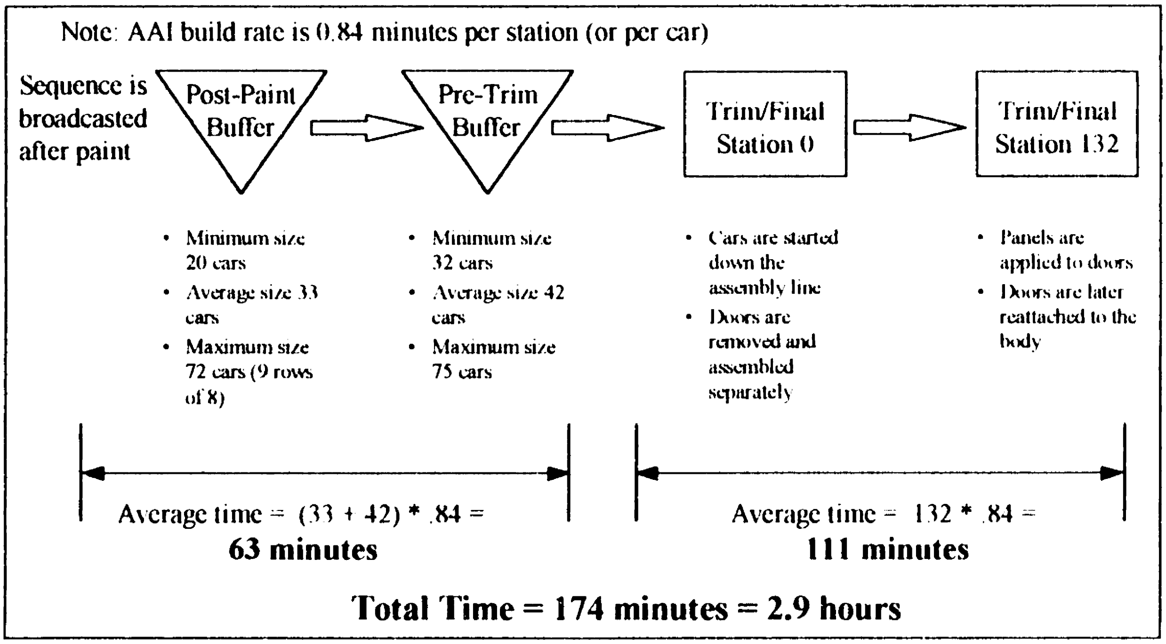
[16] The vinyl applied to the substrates comes on rolls, so there is a set-up time in changing the vinyl rolls when a different color is scheduled on the line. A flawless color change can have a zero set-up time, but this cannot be maintained over batches of one. However, the color complexity is only four. Assuming that a mechanical system could be developed which could store four rolls of vinyl at a time and be able to apply vinyl from any four of those rolls onto a door panel (eliminating the need for a person to change the color rolls), building in sequence might be a possible option from the beginning of the line.

s.k.u. is attached to the automobile. Subtracting the transportation time of 1.5 hours to AAI[17] leaves only 1.4 hours for production, loading, and unloading.

Figure 2.2-2: ST44 Lead Time From Broadcast to Part Installation



Assuming a loading and unloading time of 0.4 hours total, this leaves an hour of production time, in which about 100 panels can be produced[18] in time to be transported to the final assembly plant. During an 8 hour day, there would have to be 8 shipments, one every hour. Currently there are 2 shipments, one every 4 hours, so the new system would require 4 times more shipments with the shipment size being 1/4 the current size.

A simulation was developed to further test the feasibility of the JIT system suggested above. Details of the simulation are given in section 7.2. The simulation includes other production constraints such as scrap, rework, and downtime. The simulation results are summarized below.

- Additional inventory after the edgefolding processes reached a maximum of 156 left-hand panels, and 156 right-hand panels. This would require a buffer consisting of 7

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[17] Note that building in sequence at Utica eliminates the need for the CTI warehouse.

[18] Since the throughput rate of the Utica production line is greater than that of the AAI assembly line, the production rate would be set by the assembly plant which produces 1 car every 0.84 minutes. Furthermore, it is assumed that 70% of production is of the Ford Probe, which implies that a Probe is produced every 1.2 minutes, or 50 probes in an hour. 50 cars an hour imply 100 panels an hour.

racks (each rack contains 24 panels) for the left-hand panels and 7 racks for the right-hand panels.

- In order to help insure a high service level, finished goods inventory would also be needed to protect for downtime of the Utica process. A rack of each s.k.u. seems to be the most convenient way to handle this protective stock.

Even with such a large stock to protect for downtime and other unforeseen production problems, the finished goods inventory can be significantly reduced by this proposed process. With AAI holding finished goods to protect for transportation uncertainty and unexpected production uncertainty at the assembly plant, the total inventory in the system is[19]

Table 2.2-4: JIT Finished Goods Inventory for ST44

Utica Additional Inventory	
WIP (14 racks * 24 units)	0.42 days
Protective Inventory (34 s.k.u.'s each with a rack)	1.02 days
AAI Finished Goods Inventory	
AAI Warehouse Inventory	1.25 days
Total	**2.69 days**

Once again, there is a potential for about 1 day of inventory improvement in the supply chain. This translates into similar potential savings as calculated before in table 2.2-3. One might expect more from a JIT system, but note that the entire costs of operating the CTI warehouse have been eliminated.

The benefits and costs of the JIT system are as follows:

Benefits

- Overall system inventory reduction resulting in a potential savings of approximately that shown in table 2.2-3.
- Elimination of the all the costs of operating the CTI warehouse.
- Quality improvements resulting from less material handling.

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[19] Note that the additional work in process (WIP) inventory was included in the table. This is important since this is inventory that is not present under the current system. Even though the cost of this inventory is less than that of a finished s.k.u. (not as much labor, machine time, etc. have been put into the part), I calculate possible savings using the standard cost. Obviously, this will help give a conservative potential savings estimate.

- It has been shown that JIT systems, along with an appropriate corporate culture, can lead to continuous improvement in line processes (Nahmias, 1993, p. 746).

Costs

- Increased transportation costs due to more frequent shipping.
- Modification of the current shipping system so that parts can be shipped individually and in sequence instead of in batches of 24.
- Greater management and employee involvement in the process in order to insure on-time delivery in a short lead time environment.
- Modification of the current information technology system to keep careful track of stock levels for each s.k.u.
- Allowing ST44 shipments top priority in the shipping docks.
- The costs of a new computer system that receives broadcasts and prints labels (or a transfer of the current system from CTI).
- Training employees in the process changes.
- The cost of more production space due to the WIP buffers after the edgefolding process.

A complete analysis would quantify the above, consider feasibility issues, and make a decision based upon possible savings. Unfortunately, there are many issues which make the proposed JIT system infeasible at Utica. These issues are discussed in detail in section 2.3. However, the analysis presented provides a basis for similar calculations which can be done for different processes within the Utica plant.

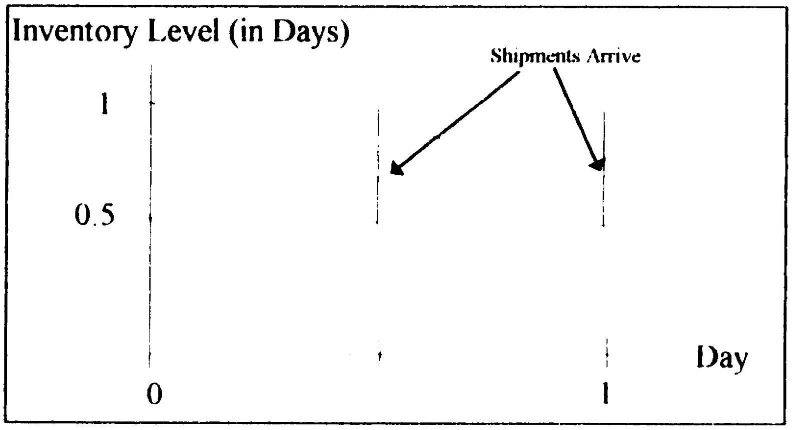
2.2.3. ILVS Investigation

As said previously, ILVS is a special case of JIT, except that instead of receiving broadcasts from the customer (the assembly plant) as orders occur, Utica would receive forecasts of demand for the next five days, each day of production. A successful implementation of ILVS implies that the sequence is 98% accurate. From the fascia analysis (see section 3.2) it is clear that an ILVS program, even in its trial phase, amounts to a significant reduction is forecast error and therefore safety stock and finished goods inventory levels.

It is not surprising to find out that the ILVS analysis is similar to that of the "broadcast JIT" analysis. Unless there are significant modifications to the vacuum-forming machine (refer to footnote 16), buffers for ILVS would once again be placed after edgefolding. Even though there is a 5-day lead time, daily production would proceed in a similar fashion to the JIT situation.

With a 5-day lead time instead of 2.9 hours, it would be possible for the production line to maintain a one-day ahead production system as described in section 2.1.2.2. Under such a system, the protective stock for downtime in table 2.2-4 is unnecessary. However, maintaining production one day ahead of schedule with two shipments occurring each day, implies an additional average finished goods inventory of approximately 0.75 days. The method of obtaining this estimate is shown graphically below.

Figure 2.2-3: Finished Goods Inventory Graph



At the start of the day there is about one day of inventory at CTI due to production trying to stay one day ahead of demand (this excludes safety stock which is calculated later). Since there are 2 shipments during the day, this inventory is drained and replenished twice. The resulting average over time is 0.75 days of inventory.

The 0.5 days of inventory in figure 2.2-3 is a result of the production system staying one day ahead. Although this is not entirely efficient, the current system operates this way and is another attempt to have a buffer which protects from shortages. As said previously, such shortages are much more costly than overstocks.

As far as safety stock goes, successful ILVS would allow for smaller safety stock levels with a higher service level. The safety stock implications of ILVS are explained in appendix 6.8. Looking at the average s.k.u. demand in table 7.1-1, one would calculate a 10% safety stock for each s.k.u. and obtain a total of about of 78 units. This is about 0.10 days of safety stock, significantly less than the amounts in figure 2.2-2.

Once again, I will leave the AAI inventory levels alone and predict the finished goods inventory levels for an ILVS system to be

Table 2.2-5: ILVS Finished Goods Inventory Levels for ST44

Utica Additional Inventory	
WIP (14 racks * 24 units)	0.42 days
One Day Ahead Stock	0.75 days
AAI Finished Goods Inventory	
AAI Warehouse Inventory	1.25 days
Safety Stock	0.10 days
Total	**2.52 days**

Although these levels were not tested explicitly, knowledge of the results from the JIT simulation helped to set the levels. Once again, this option offers about a day less of inventory combined with the removal of warehouse costs.

The benefits and costs are similar to those shown at the end of section 2.2.2. However, some of the costs have been eliminated. There is no need in this case to have transportation costs increase. ST44 shipments would no longer need top priority. There could again be two shipments per day. Once system modifications have been made, there should be no reason to assume that this system would create greater management involvement than before. Forecasts are extremely accurate over 5 days and the production system can continue to remain a day ahead of schedule. Although a new computer system would need to be developed to handle sequence stocking and building, a broadcast system would be unnecessary.

Unfortunately, AAI is not an ILVS plant, so the system above can not be implemented right now. However, the analysis can applied to other plant processes which may supply ILVS assembly plants in the future when and if ILVS is successful. Other implementation issues are discussed in section 2.3.

2.3. Results, Implementation Issues, and Recommendations

2.3.1. Overall Implementation Issues

Despite which system is analyzed for the ST44 process, there are some overall issues which might affect implementation at this point and in the future. Time constraints prevented possible trial implementation during the internship, but more importantly, the fact that the AAI assembly plant is a joint venture with Mazda impedes possible implementation. Ford seems to have little, if any, control over the entire ST44 system because of this fact. Changing base stock sizes and improving the information technology transfer between the two companies would require convincing Ford and Mazda of the savings a new system can achieve. Coupled with the fact that the Utica Trim Plant expects to lose the ST44 door panel market in two years (by 1997), makes pursuing changes in established operating procedures very difficult.

In the event the current system continues to provide successful service to AAI, it would be very difficult to convince the implementation of a new system. Although taking up less warehouse space could be a potential way to argue, the systems investigated do not improve the squeeze for warehouse space at Utica. An improvement in the current system would reduce inventory levels at CTI, and both the JIT and ILVS systems lead to more WIP at Utica which causes more problems in terms of space.

Despite these drawbacks, the analysis presented certainly provides insights into how to plan inventory reductions in processes which do not have these implementation constraints. For example, Ford Motor Company owns the entire supply chain in many other door panel processes. The potential savings in holding costs and space would affect only Ford, and it would thus be easier to attempt implementation.

2.3.2. Overall System Recommendations

Despite which system was analyzed, I recommend the system changes below to aid in any inventory reductions for the ST44 supply chain. The points can be added to the other recommendations presented in the individual system sections following this section.

- The joint venture seems to make communication to all points of the supply chain very difficult. Mazda is not connected directly to the production computer system at Ford. Just to get enough data to analyze took a lot of time and effort. There needs to be a better communication of demand so that a more effective pull system can be managed.
- Whatever the inventory control policy is, it should be clear to all levels of the supply chain instead of "blindly producing the requirements on the computer screen," as one scheduler mentioned.
- Inventory to protect for downtime and scrap can be reduced by continuous improvement efforts focused on reducing such factors. After successful reductions are made, such improvements should be quickly translated into lower inventory levels.

2.3.3. Current System Improvements

For the current system, the data indicates that a reduction of inventory is possible. I recommend a reduction goal of 1 day of finished goods inventory. A gradual reduction of inventory is recommended instead of a drastic shift from the current process. As far as the location of this inventory, there is really no reason to have the finished goods inventory in significant amounts at three locations (Utica, CTI, and AAI). Some finished goods inventory should be stored at AAI for unexpected scrap from production and/or transportation. Other than that, all of the inventory should be located at CTI, where the sequence is currently drawn. Utica's storage of finished goods inventory should be nothing more than a staging area, with a small amount of inventory to cover unforeseen production problems.

In order to aid in the gradual reduction target, the following management changes are recommended:

- Efforts could be made to reduce the forecast error in order to be able to further reduce the safety stock levels required. The Wixom forecast system (described in section 3.1.3.3) produces forecasts errors with a smaller standard deviation from zero. Perhaps such a system could be investigated for AAI, and demand forecasts could be transmitted to Utica on a daily basis, as in the Wixom case.[20]

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[20] This Wixom system is dependent upon ILVS. Implementations for ILVS at AAI are not planned.

- A base stock policy is recommended where the safety stock in the system is calculated as detailed in the analysis section.
- The mix of product may change, in which the s.k.u. demand averages change over time. In such cases, regression analyses similar to that done in appendix 6.4 can be helpful in predicting the safety stock required under a different mix of car types. In all cases, the analysis methods presented can be applied dynamically to the process again when significant changes occur.

As pointed out in section 2.1.2.2, the Utica Trim Plant was able to reduce inventory levels through reduction efforts of their own. These efforts could not achieve all the inventory reductions possible without involving AAI, but Utica could continue to reduce the 1.23 days average inventory level at its warehouse despite the details of the joint venture.

2.3.4. The JIT and ILVS Systems

In addition to the overall implementation issues presented earlier, both of these systems have some other constraints. The CTI warehouse sequences more than just ST44 panels. Mazda uses other suppliers for the Mazda RX7 and Mazda 626 door panels. The assembly line runs all three of these car lines (Probe, RX7, and 626), so the output from the CTI warehouse is a sequence of all three lines mixed together. Providing the Probe sequence from the Utica plant would require modifications of the system at CTI and AAI.

The JIT system is particular infeasible due to proposing the management of four times the number of shipments that are currently made. Drastic changes would have to occur in shipping. Furthermore, due to such a short lead time, large amounts of stock would be needed to protect for downtime. There might also be quality concerns (hurried inspections, for example) because of the "rush mind-set" stemming from having such a short lead time. No other process at Utica would require the demands that this JIT line creates. Large risks are associated with this system due to the short lead time from broadcast to when the part is applied to the vehicle. What's more, when the Probe market decreases considerably, the JIT line would be hit with unfavorable utilization numbers since the line would run at the rate of demand from AAI instead of running only a couple of shifts per week to produce the desired demand.

The ILVS system is also infeasible due to the fact that ILVS is not being pursued at AAI. Wixom is one of the few pilot plants for the system, but Ford Motor Company has stated a goal of implementing ILVS at its assembly plants worldwide. AAI, however, is a joint venture and not an entirely owned Ford plant.

If implementation were possible, however, I would recommend the ILVS system for the ST44 process. With the extended lead time, the production system can continue to operate with a one-day ahead of demand target. Furthermore, the system does not have the disadvantage of poor utilization when demand is low. Production could be done in sequence over multiple periods.

The reader should note that implementation issues do not make the analysis a waste, as it provides several key insights into the issues that a potential JIT or ILVS supplier faces. Moreover, it shows JIT potential for other lines in which the customer is located closer to the supplier, and/or the assembly plant has a longer broadcast lead time (as is the case at Wixom; see table 3.2-5).

2.4. ST44 Conclusions

Clearly, if one had the option of choosing a system for the ST44 process it would be the ILVS system. It offers a basic continuation of the current production system, except for in-sequence production after edgefolding. Furthermore, the "real savings" are obtained from supplying the assembly plant directly. The economic holding cost of inventory is hundreds of dollars a week, but the cost of operating the warehouse is hundreds of dollars a day. Considering implementation issues, however, the only real option seems to be for Utica to pursue inventory reductions in its own warehouse.

Since implementation is dubious, the analysis is the most important product of this research. For example, it was my experience, though limited,[21] that when speaking of ILVS (or JIT) there were typically only 2 choices mentioned:

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[21] The experience referenced are the two case studies in the thesis as well as discussions with another team trying to determine ILVS feasibility on a different interior door panel line.

1. Build in sequence from the start of the line to the finish, or
2. Build in batches, and pick the sequence from the batches (usually at some warehouse, whether Utica or some outside warehouse).

This analysis provides a method of looking at where the complexity additions are made in the line and analyzing the sequencing measures from various points within the line. Furthermore, the results can be directly applied to many of the other door panel lines that have similar complexity additions in the process (i.e. the vinyl application takes place first before other complexity is added).

In general, the analysis methods pursued add insight into inventory reduction efforts. Calculating safety stock levels by carefully analyzing forecast errors is another important aspect of the analysis that should prove useful to many production processes at Utica.

3. Fascia (Plastic Bumper Cover) Process

3.1. Overview

This thesis focuses on fascias that are supplied to the Wixom assembly plant. However, process and scheduling issues must include data of the other parts that are produced along with the Wixom fascias.

3.1.1. Manufacturing Process

The manufacturing process for the 1995 model year is shown in detail in appendix 6.2. The process is a bit more complex than the ST44 process in that there are four distinct sections — molding, trimming, paint, and assembly. The door panel process was mainly just an assembly operation.

Molding consists of 17 reaction injection molding (RIM) machines and 3 TPO (thermoplastic olefin) machines. Currently, only 1 TPO machine is running, but the assumed steady state for the 1995 model year is 3 machines. Parts coming from the RIM machines are then sent to trimming in order to rid the part of excess plastic material. RIM parts are then placed in a buffer waiting for paint. This analysis assumes that these parts must wait in the buffer for at least 4 hours.[1] Parts coming from the TPO machines are moved immediately to the pre-paint buffer and require no such minimum waiting time. The RIM machines experience a set-up time of 4 hours[2] between part changes, while the TPO machines have a similar set-up time of 30 minutes.

Paint is the most complex section of the fascia manufacturing process. RIM parts are taken from the pre-paint buffer and placed upon carriers. These carriers transport the parts through the paint system. RIM parts are moved throughout the post cure oven,

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[1] There is some dispute as to how long RIM parts must wait in the buffer before paint. The dispute stems from what is know as outgassing. If a recently molded part is immediately painted, gas particles within the part may escape through the paint and cause a defect. The assumption agreed upon was that 4 hours would be adequate to eliminate most outgassing problems. However, in certain written specifications for the buffer the waiting time has reached as high as 24 hours.

[2] Once again, there is some dispute over this set-up time. It seems as though if the set-up is planned in advance the time can be reduced to as little as 1 hour due to operations that can be done in preparation for a set-up. However, this thesis continues to use what is considered the "standard set-up" time of 4 hours.

which heats up the part in hopes of preventing further outgassing. Meanwhile, TPO parts are loaded into carriers before going into water wash. RIM and TPO paint batches proceed through water wash. The prime paint coat is then applied. All s.k.u.'s proceed through the system in minimum batches of 6 carriers or 12 parts.[3] These batches remain together throughout the system.

At this point, parts that have two-color sections are sent to masking while the other parts continue on to the color coat paint application. In masking, the sections that will not be receiving the second coat are covered, or masked, so that the second coat will be applied to the necessary sections of the part. The masked parts do not leave the masking area until the next batch to be masked enters the area. At that point, the masked parts continue on to the color coat application. There is a loss of one cycle (about 0.283 minutes) during a change of color at this stage in the paint line due to a cleansing of the system in preparation for a new color.

After color coat the parts proceed to clear coat and onto to unloading. Parts that need to re-painted (the next time they may receive a different color) are left on the carriers and re-enter the paint system as before (RIM to the post cure oven and TPO to the water wash). Parts are also scrapped at the unloading section of the paint system.

Parts that have been successfully painted are sent to the pre-assembly buffer. Two assembly lines retrieve part batches from the pre-assembly buffer. The lines consist of 11 stations each. Screws and other attachments are assembled to the fascias and the fascias are then sent to pack-out where they are stored and then shipped to the assembly plants. Part changes on the assembly line create set-up times that vary from 0 to 5 minutes.

3.1.2. The Wixom Supply Chain Studied

The supply chain for the Wixom fascia parts is

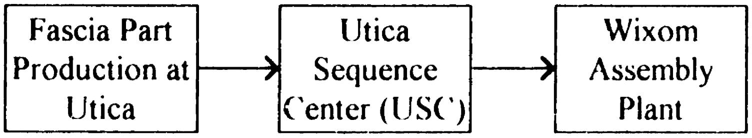

Figure 3.1-1: Wixom Fascia Supply Chain

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[3] Each carrier holds 2 parts. Some carriers hold more than 2 parts, a fact which is taken into account in the simulation (see section 8), but the carriers for the Wixom fascias all hold 2 parts.

The Utica Sequence Center is 2 hours away from Utica. The Wixom Assembly plant is about 10 minutes away from the Utica Sequence Center.[4] The Wixom assembly plant is the ILVS pilot plant for the Plastic and Trim Products Division of Ford Motor Company. Specifically, this means that plant is trying to consistently predict, every day, the next 5 days of the exact sequence of cars that it will produce with 98 % accuracy.[5] It is hoped that ILVS will give suppliers the lead time required to be able to ship in sequence to the plant and reduce finished goods inventory in the various supply chains.

During my research, Wixom was still in the trial period for the 5-day fixed sequence program. 98% accuracy was not yet achieved consistently, and the sequence accuracy varied from 80% to 99%. Due to this fact, I focus on ILVS opportunities with the current broadcast system after paint (see section 3.2.2), and mention further possibilities that a fixed sequence could achieve in section 3.2.3.

3.1.3. Current Production System

3.1.3.1. S.K.U. Complexity

The fascia process[6] produces 242 different s.k.u.'s[7] shown in detail in appendix 6.5. Each s.k.u. does not pass through all phases of the fascia production process. Explicit detail of this fact is presented in the fascia simulation section (section 8). The reader should note once again that Utica is a dynamic production environment in which some of the s.k.u.'s become obsolete and others are added. These s.k.u.'s were chosen to represent the state of the system between mid-November 1994 and early December 1994. As far as being able to represent steady state production in 1995, it is assumed that such a complexity analysis will continue to provide useful insight into production in 1995, mainly because as some s.k.u.'s are deleted, others will be added.

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[4] During the first half of the internship USC was 30 minutes from Utica and 2 hours from Wixom. The Center moved to a new location closer to the assembly plant.

[5] The details of how Wixom is trying to accomplish this are of a proprietary nature and therefore not disclosed in this thesis.

[6] I call it the fascia process although a few parts other than fascias are produced, such as rockers, caps, and spats. These parts are not ignored, but for convenience the process is labeled in this thesis as "fascia."

[7] Service parts are ignored mainly to limit the scope of the thesis. However, it was assumed that service parts could be worked into the process where excess capacity allowed, and perhaps even produced during overtime or weekend operations to meet demand if necessary.

Although the entire s.k.u. complexity is considered, recommendations and inventory analysis are restricted to the Wixom fascia parts shown below.

Table 3.1-1: Wixom Fascia Part Complexity

	Single-Tone Colors														Two-Tone Colors							
Parts Color(s)	Ivory	Pumice	Electric Currant Tint	Berry	Dark Portofino Blue	Portofino Blue	Venetian Blue	Deep Jewel Green	Evergreen Frost	Medium Willow	Ebony	Performance White	Silver Frost	Medium Graphite	Portofino Blue / Dark Portofino Blue	Dark Portofino Blue / Dark Portofino Blue	Performance White / Medium Graphite	Ebony / Medium Graphite	Electric Currant Tint / Medium Graphite	Silver Frost / Medium Graphite	Medium Graphite / Medium Graphite	TOTALS
Mark VIII Fronts	X	X	X	X	X	X	X	X	X	X	X	X	X	X								**14**
Mark VIII Rears	X	X	X	X	X	X	X	X	X	X	X	X	X	X								**14**
Continental Fronts	X	X	X	X	X	X		X	X	X	X	X	X	X								**13**
Continental Rears	X	X	X	X	X	X		X	X	X	X	X	X	X								**13**
Towncar Fronts	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	**20**
Towncar Rears	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	**20**
TOTALS	**6**	**6**	**6**	**6**	**6**	**6**	**2**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**94**

3.1.3.2. Description of the Current Production System

The paint system requirements drive the current production system. Molding looks at the general assembly plant requirements[8], tries to follow the paint schedule to insure paint is supplied with the necessary s.k.u.'s. and attempts to keep the work in process (WIP) inventory between molding and paint to a maximum of a day of inventory (in terms of a day of paint production). Each shift the molding department checks the WIP inventory level between molding and paint once or twice.

The paint system looks at the daily requirements which cannot be met from finished goods inventory, looks at the two week forecasts given on CMMS (an information technology system for production), and attempts to keep 2 to 6 days of finished goods inventory depending on the s.k.u. Production is scheduled in order to

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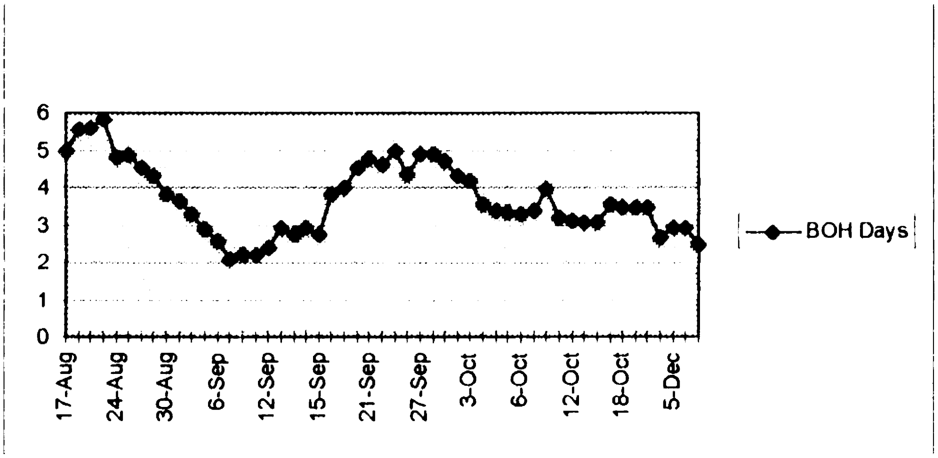
[8] Calculations are made from assembly line rates and previous demand data to determine daily requirements. Similar calculations are done for the simulation (see section 8.3).

manage the capacity of the line. Every color cannot be run every day, so depending on the daily demand requirements, the s.k.u.'s are scheduled daily, or every few days.[9]

The assembly line produces parts in batches of varying sizes but, since there is a set-up between part changes, prefers larger batch sizes especially for parts which have a smaller cycle time so that the set-up time is a small percentage of production time. Parts are shipped in racks with 4 or 6 of the same fascia s.k.u.'s. The line attempts to assemble the entire daily paint output.

The main portion of Wixom fascia finished goods inventory is stored at USC. The following two charts[10] plot the balance-on-hand (BOH) inventory at USC:

Figure 3.1-2: Days of BOH for Mark VIII Fascias at the USC



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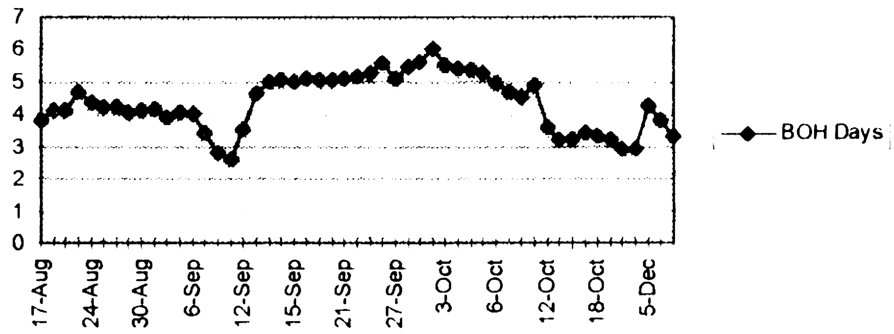
[9] Once again, a similar scheduling of parts is done for the simulation (see section 8.1).
[10] The BOH data is separated into 2 charts since Mark VIII vehicles are assembled at Wixom on a completely differently assembly line from the Continentals and Towncars. The lines have two different line rates, which is used to calculated the BOH numbers in days of inventory.

Figure 3.1-3: Days of BOH for Continental and Towncar Fascias at the USC



It is important to note that the lowest value was 2 days and that the trend in both charts is lower in the later dates. This is due in part to active inventory reduction efforts, and in part to the move of the USC to a location closer to Wixom which has less storage capacity. Similar data was collected for finished goods inventory at Wixom. Utica held inventory only temporarily before shipment to Utica, so the average BOH at Utica was essentially zero.

The following table summarizes the average BOH data (after the Utica Sequence Center move), and shows that the majority of inventory is held at the Sequence Center:

Table 3.1-2: Current Wixom Fascia Average Finished Goods Inventory Levels

Location	**Average Days of Inventory**
Utica Sequence Center	
Mark VIII	3.12
Continental and Towncar	3.40
Wixom Assembly	
Mark VIII	0.94
Continental and Towncar	0.64

This data is used as a baseline to compare with inventory reduction calculations later.

3.1.3.3. Demand Forecasting Procedure

The demand forecasts are the production forecasts from the Wixom assembly plant. These forecasts are made daily, updated daily, and extend over a 10 day time horizon (including the current production day). The data is readily available to Utica through Ford's computer production network (the Common Manufacturing Management System, or CMMS). These are the forecasts used for analysis.

3.2. Analysis

3.2.1. Supply Chain Models and Simulation

3.2.1.1. Supply Chain Mathematical Analysis

We[11] developed a model to determine a conservative level of inventories needed to account for the forecasting uncertainty from the Wixom plant. Using the analysis shown in appendix 6.3, the model for the demand uncertainty (or the standard deviation of forecast error) over the replenishment lead time for Mark VIII fascias was found to be

$$\log\left(\frac{\sigma_L}{\sigma_1}\right) = -0.173 + 0.553\log(L) + 0.369i \qquad \textbf{Equation 3-1}$$

which translates into

$$\log(\sigma_L) = -0.173 + \log(\sigma_1) + 0.553\log(L) + 0.369i \qquad \textbf{Equation 3-2}$$

where L represents the length of the replenishment lead time and i was a dummy variable (i equaled 0 when L equaled 1 through 5, and was 1 otherwise).[12] This variable accounts for the variability in the regression model due to the first 5 periods.[13] The standard deviation of the forecast error for a single period, σ_1, is different for each s.k.u. We use a different replenishment lead time, L, for each s.k.u.[14]

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[11] We refers to the author in conjunction with his thesis supervisors

[12] See appendix 6.3 for an explanation of the other variables.

[13] Considering that Wixom is the pilot plant for producing a 5-day ahead fixed sequence, such an indicator variable reflects the lower variation for these days.

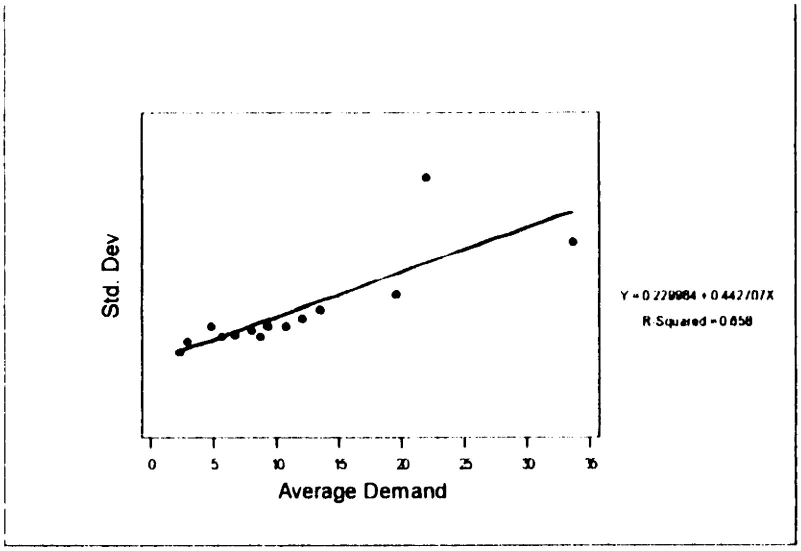
[14] The replenishment lead time varies for each s.k.u. since the paint line does not schedule each s.k.u. the same. Some s.k.u.'s are scheduled daily, while others are scheduled every few days due to capacity constraints.

Equation 3-2 verifies relationships that were suspected. Mainly, as L increases so does forecast error. As the forecast error over one period increases (σ_1), so does the forecast error over the lead time. And finally, Wixom forecasts beyond the 5 days are subject to more error as shown by the positive coefficient of the indicator variable (i).

The model accounts for approximately half of the variation in the regression (the R^2 statistic is equal to approximately 0.5). Although a higher R^2 statistic is desired, the model was considered adequate for determining a conservative estimate for the safety stock levels. An analysis of the residuals (shown in appendix 6.6) was done to further test the validity of the model. Additionally, forecast error data not used to form the model was used for validation. For conservative calculations of the necessary safety stock levels, no significant variations from the model was present.

Note that the model examines all of the s.k.u.'s over multiple time periods simultaneously. The σ_1, or the standard deviation of the forecast error for a single period (for each s.k.u.), allows the model to be extrapolated for any individual s.k.u. Such extrapolation is important due to the fact that s.k.u.'s with a higher average demand typically have higher forecast error variations. This relationship was apparent with door panels (see appendix 6.4), and is also apparent in the Mark VIII s.k.u.'s as shown by the positively sloped regression line in figure 3.2-1.

Figure 3.2-1: Relationship Between Standard Deviation of Forecast Error and Average Demand



Using the model, I calculated the safety stock levels needed to account for forecast error over the replenishment lead time for each s.k.u. The following table is derived from the model represented by equation 3-2 and the method presented in appendix 6.3 (k was set to 98% and the replenishment lead times, L, were based on the scheduling frequencies of each part shown in section 8.1):

Table 3.2-1: Mark VIII Calculated Safety Stock Levels[15]

S.K.U.	Safety Stock
MARK FRT BMPR IVORY	2
MARK FRT BMPR PUMICE	4
MARK FRT BMPR ELEC CRNT TINT	2
MARK FRT BMPR BERRY	2
MARK FRT BMPR DK PORTOFINO	3
MARK FRT BMPR PORTOFINO	4
MARK FRT BMPR VENETIAN BLUE	3
MARK FRT BMPR DP JEW GRN	2
MARK FRT BMPR EVERGREEN	3
MARK FRT BMPR MED WILLOW	3
MARK FRT BMPR EBONY	7
MARK FRT BMPR PERF. WHITE	3
MARK FRT BMPR SILVER FROST	6
MARK FRT BMPR MED GRAPHITE	4
Total Safety Stock Units	**49**
Daily Requirement	**128**
Days of Safety Stock	**0.38**

Based on the model, only 49 fascias should be the average inventory level which protects for this forecast uncertainty. As shown above, the forecast error seems to be quite accurate, just as management of any assembly plant would have hoped their production plans to be. Comparing this with table 3.1-2, with a level of 3.12 days of inventory for Mark VIII's there might be a possibility for inventory reductions. However, other production factors such as batching, scrap, downtime, and scheduling constraints must be considered and are through simulation.

In a similar fashion, I developed models of forecast uncertainty and calculated safety stock levels for the Continental and Towncar fascias. The model for the demand uncertainty, or the standard deviation of forecast error over the replenishment lead time for the Continental and Towncar fascias was found to be

$$\log(\frac{\sigma_L}{\sigma_1}) = -0.163 + 0.453\log(L) + 0.374i \qquad \textbf{Equation 3-3}$$

which translates into

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[15] Since fronts and rears are put on every car, only the fronts are shown in the table. The rears would give similar results.

$$\log(\sigma_t) = -0.163 + \log(\sigma_1) + 0.453\log(L) + 0.374t \quad \textbf{Equation 3-4}$$

I calculated the safety stock levels needed to account for forecast error over the replenishment lead time for each s.k.u. The following table is derived from the model represented by equation 3-4 and the method presented in appendix 6.3 (k was set to 98% and the replenishment lead times, L, were based on the scheduling frequencies of each part shown in section 8.1):

Table 3.2-2: Towncar and Continental Calculated Safety Stock Levels

S.K.U	Safety Stock (Units)
T/C FRT BMPR-IVORY 3C	9
T/C FRT BMPR-PUMICE	8
T/C FRT BMPR-ELEC CUR TINT	11
T/C FRT BMPR-BERRY	5
T/C FRT BMPR-DK PORTOFINO	6
T/C FRT BMPR-PORTOFINO	6
T/C FRT BMPR-DEEP JEWEL GREEN	8
T/C FRT BMPR-EVERGREEN FROST	6
T/C FRT BMPR-MED WILLOW	16
T/C FRT BMPR-EBONY	8
T/C FRT BMPR-PERF WHITE	17
T/C FRT BMPR-SILVER FROST	14
T/C FRT BMPR-MED GRAPHITE	12
T/C FRT BMPR-PORT/DK PORT	3
T/C FRT BMPR-DK PORT/DK PORT	6
T/C FRT BMPR-WHITE/M GRAPH	8
T/C FRT BMPR-EBONY/M GRAPH	8
T/C FRT BMPR-ELEC CUR/M GRAPH	6
T/C FRT BMPR-SILVER FRS/M GRAPH	27
T/C FRT BMPR-M GRAPH/M GRAPH	12
CONT FRT BMPR IVORY	12
CONT FRT BMPR PUMICE	11
CONT FRT BMPR ELEC CURR TINT	9
CONT FRT BMPR BERRY	7
CONT FRT BMPR DK PORTOFINO	7
CONT FRT BMPR PORTOFINO	5
CONT FRT BMPR DP JEWEL GREEN	10
CONT FRT BMPR EVERGRN FRST	4
CONT FRT BMPR MED WILLOW	12
CONT FRT BMPR EBONY	12
CONT FRT BMPR PERF WHITE	10
CONT FRT BMPR SILVER FROST	10
CONT FRT BMPR MED GRAPHITE	7
Total Safety Stock Units	312
Daily Requirement	688
Days of Safety Stock	0.45

Just as in interior door panels, some of the difference in inventory levels can be attributed to batch production, production uncertainties, and transportation uncertainties (Graves, 1988, p. 67). These issues (except for transportation uncertainties) are addressed through simulation of the fascia process. Such a simulation will show how paint system variation and other factors can affect the inventory levels and help to recommend new average inventory targets given the current production constraints.

3.2.1.2.Simulation Analysis

Simulation of the supply chain was run under the assumptions and conditions described in section 8. These conditions included production constraints such as scrap, downtime, varying machine cycle times based on the s.k.u. being processed, paint system first-run yield, and others. As expected, the average finished goods inventory was increased above the safety stock levels due to the inclusion of these factors. The simulation resulted in an average system finished goods inventory of shown in table 3.2-3.

Table 3.2-3: Fascia Average Finished Goods Inventory Levels from Current System Simulation

Location	Average Days of Inventory
Utica Sequence Center	
Mark VIII	2.35
Continental and Towncar	2.50
Wixom Assembly	
Mark VIII	0.94
Continental and Towncar	0.64

Note that the simulation did not attempt to reduce the average inventory levels at the assembly plants. These levels should be based upon transportation uncertainty and assembly plant production uncertainty, two factors I did not analyze.

The end result is that Mark VIII inventory can be reduced by 0.77 days, and Continental and Towncar fascia inventory can be reduced by 0.9 days. Using the average standard cost of Mark VIII fascias ($85), and the average standard cost for Towncar and Continental fascias ($15) one can calculate the following potential economic annual savings due to the inventory reduction suggested by table 3.2-3:

Table 3.2-4: Potential Wixom Fascia Inventory Savings for Current System

Fascias	Reduction (in days)	Daily Demand	Yearly Savings

Mark VIII	0.77	128	$1553.66
Continental and Towncar	0.90	688	$1473.70

These saving do not include other advantages of inventory reduction, such as less warehouse space.

3.2.2. JIT Investigation

Stated once again, the first step in analyzing JIT possibilities is to determine where in the system s.k.u.'s can be sequenced according to the production sequence at the assembly plant. Fascia parts and storage racks are extremely large, so it would be infeasible to consider automobile assembly line workers picking from batches next to the line. Considering the supply chain analysis in section 3.2.1 as adequate for determining the feasibility of the current situation (sequencing from batches at an external warehouse) and a similar situation of sequencing finished goods in warehouse space at Utica, only one option is viable.

In terms of s.k.u. complexity, the only complexity added to a molded part is the painted color.[16] Furthermore, parts are molded in batches with large set-up times for RIM machines when there is a part change. TPO machines also mold parts in batches. Thus, the first opportunity to pull the sequence would be at the beginning of the paint line. However, the paint system has a has minimum color batch size requirement and painting in sequence would require the ability to paint parts in color batches of 1. The fascia assembly lines, then, produce the first and only possibility (outside of the current system) for pulling daily sequence requirements.

As shown in table 3.2-5, the broadcast lead time for Wixom fascias is much greater than for ST44 interior door panels. Taking the shortest broadcast lead time and subtracting the 2.0 hours for transportation to Wixom and 1 hour for loading and unloading, still leaves 6.21 hours for assembling the fascias. Given the fact that an assembly line for Wixom fascias, in the worst case (the part that has the largest cycle time to assembly), can assembly 120 fascias per hour (or 60 car sets per hour), the pace of the

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[16] The sub-parts (such as screws, brackets, etc.) assembled to the fascias do not add to the complexity, as these sub-parts are the same for all parts. For example, regardless of color, all Towncar fronts have the same sub-part attachments.

automobile assembly lines would dictate the pace of the Utica assembly line. In 6.21 hours, 267 Towncar plus Continental fascias and 50 Mark VIII fascias can be assembled.

Table 3.2-5: Wixom Fascia Lead Time From Broadcast to Part Installation

	Pre-Trim Buffer	Trim Line WIP	Final Line Storage Bank	WIP Until Front is Installed	WIP Until Rear is Installed	Line Rate (Jobs/Hr)	Time from Broadcast to Earliest Intallation (Hrs.)
Towncar (80%)	75	228	90	62	62	43	**10.58**
Continental (20%)	75	228	90	40	3	43	**9.21**
Mark VIII	14	60	12	5	3	8	**11.13**
Towncars and Continentals are produced on a separate assembly line from Mark VIII's.							

This analysis assumes that a new line is installed to assemble fascias in sequence to Wixom. The costs of such a line should be precisely determined to weigh against the benefits of assembling fascias in sequence. The other parts assembled at Utica are assembled on the same two lines as before. The reason for this assumption is that it would be infeasible to build to sequence at the fascia assembly line for the Wixom assembly plant and not for the other parts. Building to sequence requires an entirely different production algorithm from the current system, so an entirely new line was assumed. Furthermore, the addition of a new fascia assembly line (although not specifically for JIT) is currently being investigated by the industrial engineering department within Utica.

A simulation was developed to further test the feasibility of the JIT system suggested above. Details of the simulation are given in section 8.2. The simulation includes the current production constraints such as scrap, paint first-run yield, downtime, and others. The inventory level results from the simulation are summarized below:

Table 3.2-6: Fascia Average Finished Goods and Increased WIP Inventory Levels from JIT System Simulation

Location	**Average Days of Inventory**
Utica	
Mark VIII	1.99
Continental and Towncar	2.08

Wixom Assembly	
Mark VIII	0.94
Continental and Towncar	0.64

Note that the inventory levels include the increase in WIP which must be held in the buffer in front of the Utica assembly line for Wixom fascias. The inventory levels have decreased from table 3.2-3 mainly because the assembly line now receives 100% accurate broadcasts from the assembly plant instead of producing in batches.

The benefits and costs of the JIT system are as follows:

Benefits

- Overall system inventory reduction resulting in a potential savings slightly greater than that shown in table 3.2-4.
- Elimination of all the costs of operating the USC warehouse.[17]
- Quality improvements resulting from less material handling.

Costs

- The cost of a new assembly line for use with only the Wixom fascias.
- The costs of a new computer system that receives broadcasts and prints labels (or a modification and transfer of the current system).
- Modification of current shipping system at Utica so that parts can be shipped individually in racks, instead of one rack containing all of the same s.k.u.'s.
- Training employees in process changes.
- Modification of the current information technology system to keep careful track of stock levels of each s.k.u.
- The cost of more production space for the storage racks in the pre-assembly buffers at Utica, and the space taken up by a new line.

A complete analysis would quantify all of these values as well as take into account implementation issues which are described in section 3.3.3.

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[17] Actually, much of these costs would be taken up by the new system.

3.2.3. ILVS Investigation

Just like the case for the ST44 process, the ILVS analysis is very similar to the JIT analysis done in the previous section. Given the paint system constraints of minimum batches and the paint system's scheduling constraints with the many s.k.u.'s that must be processed, the only option for ILVS and JIT (barring changes in the paint system) is to once again have another ILVS assembly line for the Wixom fascias. Therefore, even though there is an extended 5-day lead time with ILVS, daily production would proceed in a similar fashion to the JIT situation.

The predicted safety stock implications of a successful ILVS system are explained in appendix 6.8. This would imply a safety stock of 42 Mark VIII fascias and 251 Continental and Towncar fascias which translates into 0.33 and 0.36 days of safety stock respectively. Notice that this is a little lower than the safety stock values calculated in tables 3.2-1 and 3.2-2. This makes sense, since those tables are based upon an ILVS system that had not reached the 98% accuracy level at the time this thesis was written.

Since the same production scheme used in the JIT situation applies to the ILVS system, I predict the following average inventory levels which include the safety stock figures calculated above.

Table 3.2-7: Fascia Average Finished Goods and Increased WIP Inventory Levels for ILVS System

Location	**Average Days of Inventory**
Utica	
Mark VIII	2.32
Continental and Towncar	2.44
Wixom Assembly	
Mark VIII	0.94
Continental and Towncar	0.64

Although these levels were not tested explicitly, knowledge of the simulation results from the JIT analysis helped to set the levels. Note also that the levels at the assembly plant were not decreased due to the fact that the transportation and assembly plant production uncertainties were assumed constant despite which system is in place.

The benefits and costs of this system are almost a duplicate of those presented in section 3.2.2 except for a couple of changes. First, ILVS obviously provides some security with personnel to know that they have days to work with instead of hours. Second, the costs of a broadcast system would be unnecessary. Note, however, that ILVS may not realize its full potential due to the production characteristics of the paint system prior to the fascia assembly lines. Due to batching,[18] the paint system is unable to paint in sequence. Other production systems may not have such constraints and might benefit more from an ILVS system.

3.3. Results, Implementation Issues, and Recommendations

3.3.1. Overall System Recommendations

Despite which system was analyzed, I recommend the system changes below to aid in any inventory reductions for the fascia supply chain. The points can be added to other recommendations presented in the individual system sections following this section.

- The inventory tracking system on Ford's information system should be improved so that poor data validity is not an issue. There was some concern by paint system personnel that finished goods inventory numbers at USC and/or Wixom were not accurate.
- Currently, the plant production system does not take into account forecast error in the allocation of safety stock. It has been the policy to produce a group of items up to a pre-determined time supply, B, when its forecasted lead time demand drops below a certain time supply, A.[19] For example, one fascia s.k.u. may have an inventory target between 2 and 4 days. This policy "fails to take into account the differences in uncertainty from item to item" (Silver, 1985, p. 263).

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[18] Note that many factors lead to this batching. Some of the factors are an inability to paint every s.k.u. demanded every day, a minimum batch size to help maintain a higher first-run yield, and a goal to minimize volatile organic compounds released by the plant which are released during color changes.
[19] B is greater than A.

- The paint system should try and change the even number carrier constraint.[20] I am not sure about the current feasibility of such a change,[21] but it could further increase the capacity of the paint system. This could lead to lower s.k.u. scheduling frequencies, resulting in a shorter lead time for some s.k.u.'s and a smaller amount of safety stock.
- The plant has begun the development of a computerized scheduling system for the paint system. This system includes tracking each s.k.u.'s first-run yield, as well as providing the details of a production system. The data yielded from such a system could be linked to the inventory reduction possibilities presented here. Furthermore, the data could be inputted into further simulation studies in an effort to continue to reduce finished good inventory levels as well as WIP.[22]
- The data from the new computerized scheduling system could also help address paint system variability. Variability of the paint line was not a specific focus of this thesis but was addressed in the simulation studies I conducted by the use of a uniform random variable centered on a 0.75 first-run yield value (refer to the simulation description in section 8.1). "The enemy of all mass production is variability" (Box, 1988, p. 8). The data from the new system could not only provide more accurate information for further simulation studies, but could also provide a convenient data collection mechanism for experimental designs aimed at reducing paint system yield variability.[23] Less yield variability would lead to easier scheduling and less variability in finished goods inventory at later points in the supply chain.

3.3.2. Current System Improvements

Once again, I recommend a gradual inventory reduction for the Wixom fascias. The inventory reduction goals presented in table 3.2-3 represent a good first target, but it should not be assumed that these levels represent a minimum. As forecast errors continue

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[20] This constraint might be able to be changed without changing the minimum carrier constraint of 6.

[21] Two paint system personnel indicated that a change in the logic of the paint system might provide a solution.

[22] At the time this thesis was written, a project was going on whose goal was to try and reduce WIP inventory levels.

[23] There are many books on experimental design. Such methodologies are not a focus of this thesis, but a good reference for such design is Understanding Industrial Designed Experiments shown in the bibliography.

to decrease (assuming ILVS continues toward the 98% goal) and as improvements continue to be made in the paint system and other production processes, finished goods inventory could be reduced below these levels.

Considering the relatively short replenishment lead time for s.k.u.'s and low forecast errors coming from Wixom five days ahead of production, such inventory reduction goals are within reach. There are no real capacity matching problems. Total assembly plant demand does not suddenly increase during steady state production days. Demand for one s.k.u. might change, but since the production rate for an entire assembly plant remains relatively fixed, another s.k.u.'s demand would shift in the opposite direction.

3.3.3. The JIT and ILVS Systems

Unfortunately, both of these systems have a problem with implementation. Utica simply does not have the extra space to store and handle the additional WIP generated from a buffer in front of an additional assembly line. It has yet to be established whether or not another assembly line is feasible at this point. However, once again the analysis provided is useful for plants where such space is not limited.

Clearly though, if space were not limited at Utica the JIT or ILVS systems would be preferred over the improvements in the current system due to a greater potential for savings. The economic potential savings for the current system improvements are over a thousand a year, while the ability to supply in sequence directly from a supplier plant could save over a thousand a week.

The choice between JIT and ILVS is much more difficult in the fascia case. ILVS provides a much greater lead time, but it is unclear whether this lead time would be of particular benefit. Considering the fact that the current production system at Utica calls for an average of 20 shipments of Wixom fascias sent to USC (and later to Wixom) per day, there is approximately one shipment every 0.8 hours.

In the worst case, the JIT system has 6.21 hours of production time before a delivery should be made which provides enough time to continue the shipments as currently scheduled. Furthermore, a large protection for downtime is not as important in either the JIT or ILVS case. The assembly lines are labor intensive with a small amount of downtime in comparison to the ST44 processes for example. Thus I recommend the JIT broadcast system as opposed to the ILVS system. This recommendation is also coherent with another implementation difficulty with the ILVS system. Due to the large size of fascias, even if ILVS is successful it is currently unclear whether Wixom will account for the 2% difference in sequence.[24] Furthermore, the JIT system could be converted to an ILVS system with little difficulty. The only difference being a switch from JIT broadcasts to ILVS forecasts.

ILVS is a similar system which would not have the cost of broadcast equipment installation, but due to the problems of storing fascias at Wixom, I would recommend the pursuit of the JIT option. However, ILVS might be a better system when *all* of Utica's assembly plant customers have a successful ILVS system installed. There is still the issue of space at these assembly plants to make up for the 2% sequence error of ILVS, but the system would provide for better production at Utica.

If each of Utica's assembly plant customers were able to achieve the ILVS 5-day fixed sequence, it may be possible to build in sequence given such a lead time, but one can imagine the complexity of sequencing and shuffling parts going to seven different customers and trying to satisfy over seven different sequencing demands with only 3 lines at Utica. Without such a lead time, implementing ILVS would require relying on broadcasts and would result in an assembly line for each automobile assembly plant. Perhaps the fascia assembling operation could be moved out to the assembly plants and into the sequencing warehouses.

3.4. Fascia Conclusions and Future Issues

Ignoring part size implementation issues presented above, clearly the potential impact of JIT for fascias would be the method of choice. There are meager savings of inventory reduction with the current system compared to the potential savings that JIT could accomplish. Taking the issues into account, however, leads one to pursue the

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[24] Wixom would have to have a place to store fascias for cars that are out of sequence, and be able to retrieve these fascias when the delayed car comes down the line.

reduction goals presented for the current system. The analysis presented, though, should give insight into the implementation of JIT in processes that are not limited by part size.

Note that one reason JIT building to sequence at the fascia assembly line is feasible for Wixom is because the transportation time to the plant is only 2.0 hours. However, if such a system were implemented for the Atlanta assembly plant in which parts travel by rail from Michigan, JIT would be impossible to do without several days of accurate sequence forecasts.

4. Conclusions

The following list summarizes the general conclusions that are presented in this thesis:

- The current production systems for both Wixom fascias and ST44 door panels can provide equivalent customer service with less finished goods inventory. Furthermore, the analysis presented provides plant management with a method for further inventory reduction in other plant processes.
- Even in its testing phase, ILVS reduces forecast error for the Wixom fascias. This should directly result in lower safety stock levels and therefore reduce finished goods inventory levels.
- ILVS could provide an opportunity for a tightly coupled JIT system implementation for the ST44 door panel process, and door panel processes which have similar characteristics.
- There are ILVS and JIT opportunities for fascias, but the large size of the parts coupled with the lack of space available in the plant to store more inventory, makes implementation unfeasible at this point in time.
- There are similar JIT possibilities without ILVS for the ST44 door panel process, although other implementation factors affect feasibility at this point.
- Despite a lack of feasibility for some of the aspects covered by this thesis, the analysis presented provides plant management with a method for investigating ILVS and JIT opportunities for other processes within the plant.

The length of the internship prevented a trial implementation of the ideas presented in these thesis. Significant changes in established operating procedures, like the JIT and ILVS systems, would require much more than six months to get up and running. The author realizes that simulation is not 100% accurate. Although it is used to test the initial feasibility assessment of the ideas and production systems presented, only actual implementation can work out all the necessary details of such systems. As with all implementations, significant management attention should be focused on the implementation in order to deal with problems. If early failures occur because of a lack of managerial effort, new systems could be eliminated without an adequate trial period.

4.1. *Supply Chain Comparison Conclusions*

The conclusions and analysis point out several of the important issues involved in general inventory reduction efforts, as well as in JIT and ILVS systems. Looking at the two supply chains also gives insights into how these issues affect the decision of what production system is recommended for implementation. The supply chains also point out similar characteristics across inventory reduction efforts.

In particular, I recognized the following:

- An ILVS system provides a high service delivery system when broadcast lead times are short and when production constraints such as downtime and scrap would prevent a "broadcast JIT" system from achieving high service levels without a significant amount of inventory (WIP and/or finished goods). It is also useful when transportation times are long enough to prohibit the JIT system.
- A "broadcast JIT" system provides high service delivery for systems where the broadcast lead time minus transportation time is significantly greater than the time from the beginning of sequence production to shipment.
- For both supply chains, potential economic savings seem much greater in the JIT or ILVS systems than reduction efforts of the current systems.

4.2. *Further Research Suggestions*

As a continuation of the ideas presented here, I suggest further research into the following areas:

- The results and conclusions of this thesis give hints on how to design an assembly process that could potentially save a large amount of inventory costs by allowing easier JIT system implementations. That is, for the expensive sub-component parts on an automobile, the longer after the painting section the assembly plant can delay the attachment of these parts, the longer broadcast lead time suppliers have to build and ship in sequence without loss of service levels. Extensive cost analyses could be conducted at the assembly plant level to determine if the costs of additional buffers at the assembly plant placed in order to extend broadcast lead time, could be overcome by the benefits of suppliers being able to supply in sequence successfully. Such an analysis is beyond the already large scope of this thesis, but is a possible extension.

- Future research could investigate a larger portion of the supply chain. For example, raw materials for the Utica processes could be included and/or inventory in dealerships.
- This thesis attempts to reduce inventory but did not search for the absolute minimum levels of inventory needed to provide high service to the assembly plants. Other research could attempt to find more specific optimal levels and production algorithms.
- There are plenty of opportunities for specific ways to reduce inventory with the processes. For example, investigate the problems of variation with the paint system and take steps to reduce this variation. Continuous improvement efforts within the plant will lead to such investigations.
- There could be investigations into production aspects considered constraints in the thesis to see if these constraints can be improved. For example, should the paint line supply various automobile assembly plants, can the vacuum-forming machine be modified to apply vinyl in a batch size of one, etc.
- There is certainly more room for cost analysis. This thesis did not quantify all the costs of the different systems.
- Finally, research could be conducted into how to handle non-steady state production during model changeovers and ways to efficiently handle service part production and demand.

5. Bibliography

Barnett, Arnold. Applied Statistics. Prentice-Hall. Book forthcoming, 1995.

Box, George, Soren Bisgaard, and Conrad Fung. "An Explanation and Critique of Taguchi's Contributions to Quality Engineering." Quality and Reliability Engineering International. May 1988.

Graves, Stephen C. "Safety Stocks in Manufacturing Systems." Journal of Manufacturing and Operations Management. Vol. 1. New York, NY: Elsevier Science Publishing Co., Inc., 1988.

Hall, Robert W. Zero Inventories. Homewood, Ill.: Dow Jones-Irwin, 1983.

Hall, Robert W. Attaining Manufacturing Excellence. Homewood, Ill.: Dow Jones-Irwin, 1987.

Hanssmann, Fred. Operations Research in Production and Inventory Control. New York: John Wiley and Sons, Inc, 1962.

Hay, Edward J. The Just-In-Time Breakthrough: Implementing the New Manufacturing Basics. New York: John Wiley & Sons, 1988.

Hogg, Robert V. and Johannes Ledolter. Applied Statistics for Engineers and Physical Scientists. New York, NY: Macmillan Publishing Company, 1992.

ILVS: Awareness Training Manual. Ford Motor Company, Plastics and Trim Products Division.

ILVS: PTPD Launch and Training Manual. Ford Motor Company, Plastics and Trim Products Division.

Kimball, G.E. "General principles of inventory control." Cambridge, MA: Arthur D. Little, Inc.

Klein, Janice A. "A Reexamination of Autonomy in Light of New Manufacturing Practices." Boston, MA: Harvard Business School, 1991.

Magee, John F., William C. Copacino, and Donald B. Rosenfield. Modern Logistics Management: Integrating Marketing, Manufacturing, and Physical Distribution. New York: John Wiley & Sons, 1985.

Maruyama, Takashi. The Kanban Systems and Its Characteristics. Thesis for Master of Science in Management. Massachusetts Institute of Technology, 1982.

Minitab. Computer software. Minitab, Inc., 1994.

Mishina, Kazuhiro. "Toyota Motor Manufacturing, U.S.A." Boston, MA: Harvard Business School, 1992.

Moore, David S. and George P. McCabe. Introduction to the Practice Statistics. New York, NY: W.H. Freeman and Company, 1993.

Nahmias, Steven. Production and Operations Analysis. Boston, MA: Irwin, 1993.

Renden, Barry and Ralph M. Stair, Jr. Quantitative Analysis for Management. Fourth Edition. Boston, MA: Allyn and Bacon, 1991.

Silver, Edward A. and Rein Peterson. Decision Systems for Inventory Management and Production Planning. Second Edition. New York: John Wiley & Sons, 1985.

Simulation Case Studies. Ford Motor Company, Advanced Manufacturing Systems Development and Engineering Department.

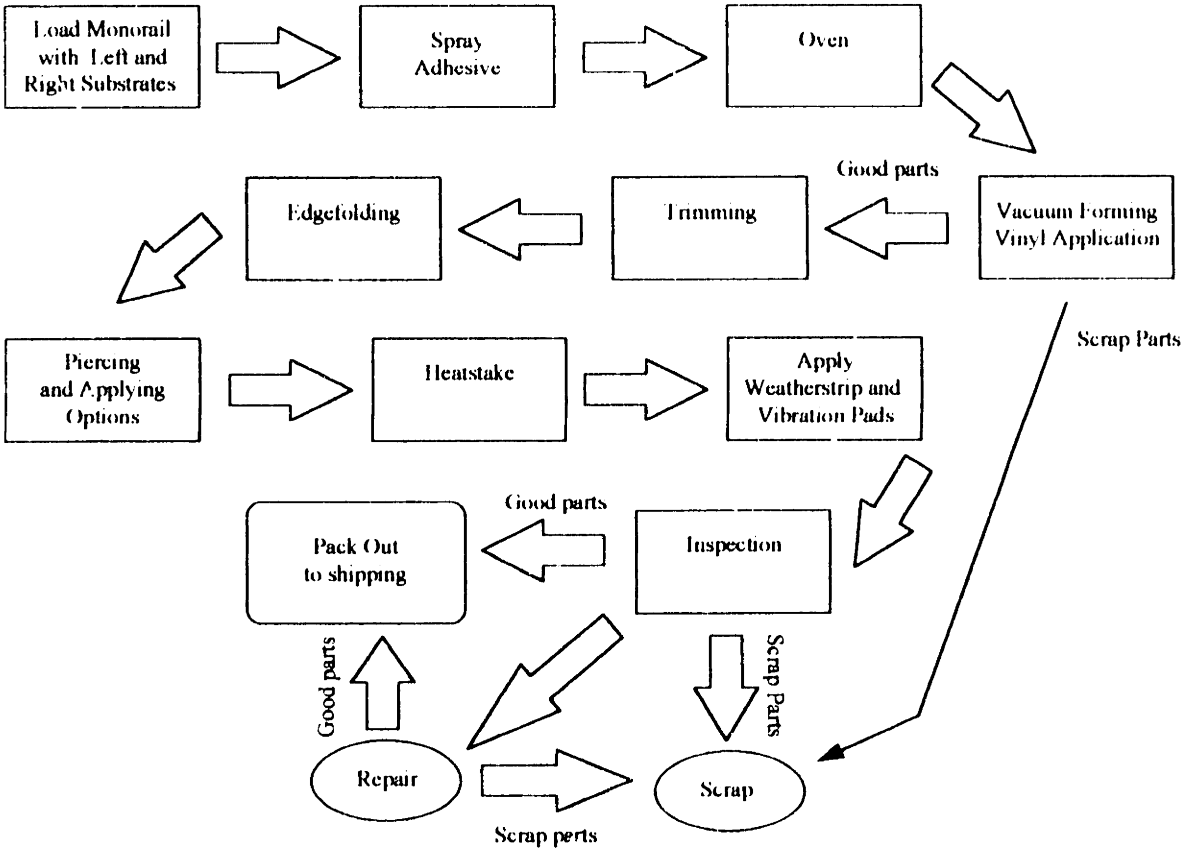
Schmidt, Stephen R and Robert G. Launsby. Understanding Industrial Designed Experiments. Third Edition. Colorado Springs: Air Academy Press, 1992.

Witness. Computer software. AT&T Istel, 1994.

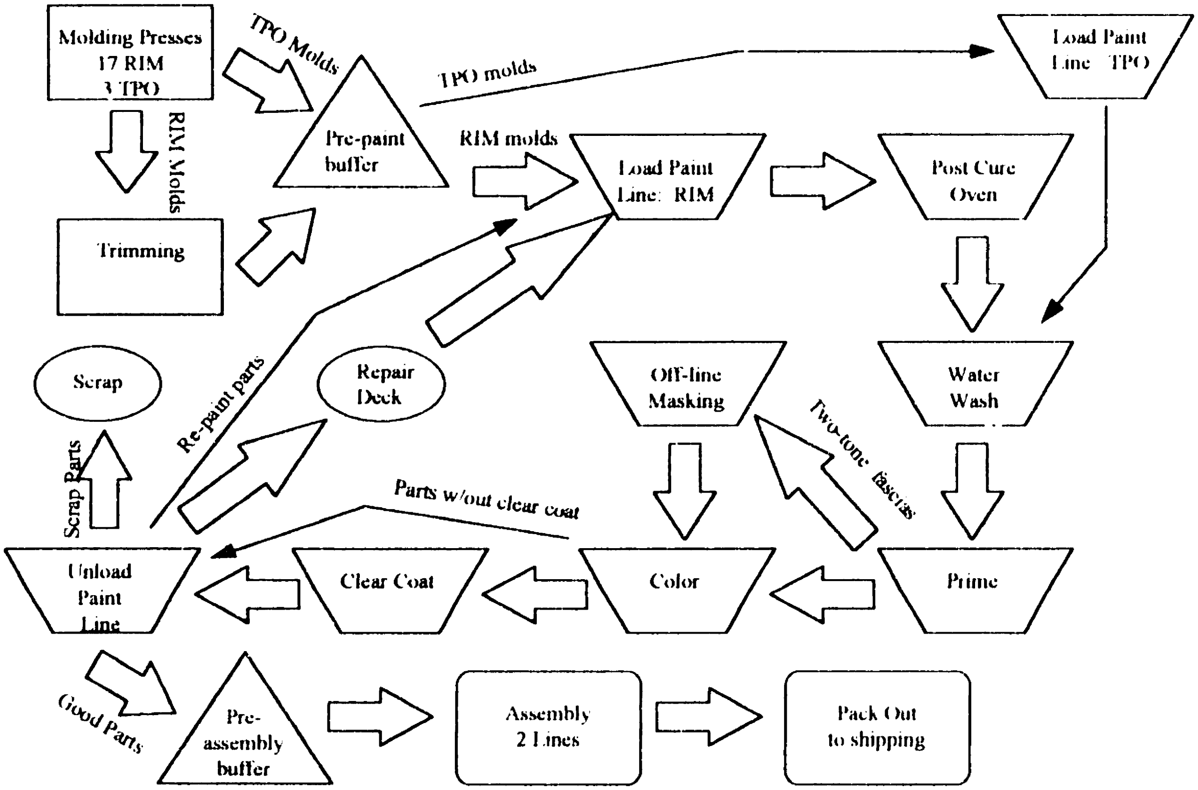
Womack, James P., Daniel T. Jones, and Daniel Roos. The Machine that Changed the World. New York: HarperPerennial, 1991.

6. Appendices

6.1. *ST44 Interior Door Panel Production Process for the 1995 Model Year*



6.2. Fascia Production Process for the 1995 Model Year



6.3. *Estimation of End Item Safety Stock Due to Forecast Error*

A period, L, was defined as being a day. In order to determine the safety stock needed to account for forecast error and a given service level, one needs to find σ_L, the variation of forecast errors over the replenishment lead time. The following model is a reasonable relationship. σ_1 is the variation of the forecast errors for forecasts for a single period of demand.

$$\sigma_l = L^c \sigma_1 \qquad \textbf{Equation 6-1}$$

where c is to be some constant found empirically.[1]

For the case of fascias, we found that the model (equation 6-1) did not accurately describe the forecasting system. We ran a regression which included an indicator variable that statistically separated the data during the first 5 periods from the last four periods. The forecast error standard deviations showed a clear change between the two data sets. Furthermore, knowing that Wixom is most likely forecasting differently over the first five periods (Wixom is trying to predict a fixed forecast over these periods) gives further justification of the use of i. The specific models used are shown in the text.

Assuming that the forecast errors over the lead time are normally distributed with a mean of 0 and a standard deviation of σ_L (an assumption that was tested and verified by viewing histograms of the data as well as using a χ^2 test) one can approximate the necessary safety stock level (SS) as being[2]

$$SS = k\sigma_l \qquad \textbf{Equation 6-2}$$

where k is a service factor determined from a normal curve as shown below:

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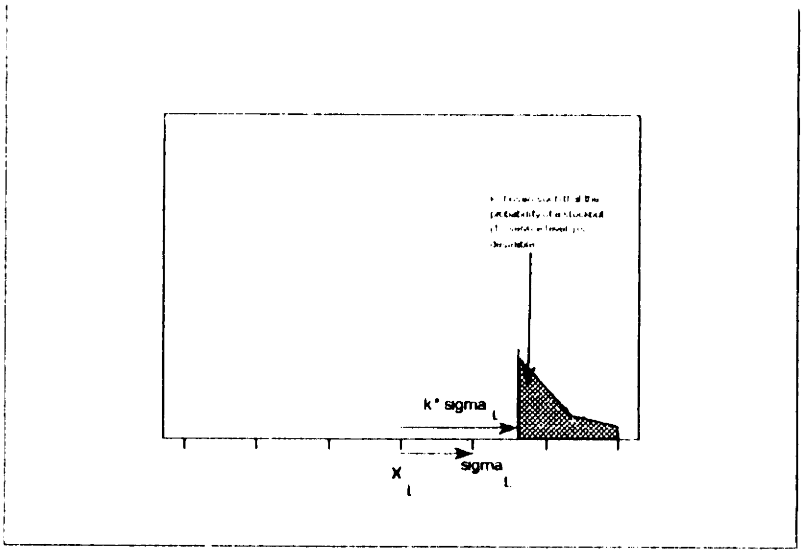
[1] For further explanation, see Silver and Peterson p. 131 or Nahmias p. 266.

[2] For further explanation of how this is appropriate see Silver and Peterson pp. 270-272 or Graves pp. 73-76.

Figure 6.3-1: Probabilistic Distribution of Demand



X_L, is the forecast over period L.

6.4. *Predicting ST44 Forecast Error Data for the 1995 Model Year*

Since forecast error data was not available for the 1995 model year, I devised a method to give an accurate projection of what the data would produce in 1995 assuming no drastic changes in the forecasting process.

Average demand data during the 1995 model year being available, I tried to quantify the relationship between the forecast error standard deviation and the average demand during 1994, and then apply this relationship to the average demand data in 1995.

It is common knowledge to expect the forecast error (demand - forecast) to increase for higher demand volumes. For example, one might expect an error of 10 for a product that has an average demand of 100 units (a 10% error), but be horrified if the error were 10 for a product with an average demand of 10 units (a 100% error). This relationship was tested through a linear regression.

Mathematically, I hypothesized the following equation:

$$\sigma_1 = A\bar{x}^c \qquad \textbf{Equation 6-3}$$

Where σ_1 is the forecast error standard deviation for forecasts done 1 period ahead, x is the average demand of an s.k.u. and A and c are constants. Similarly, we have that

$$\log(\sigma_1) = \log(A) + c\log(x) \qquad \textbf{Equation 6-4}$$

Linear regression produced the following results:

Figure 6.4-1: Forecast Error Standard Deviation Vs. Average Demand

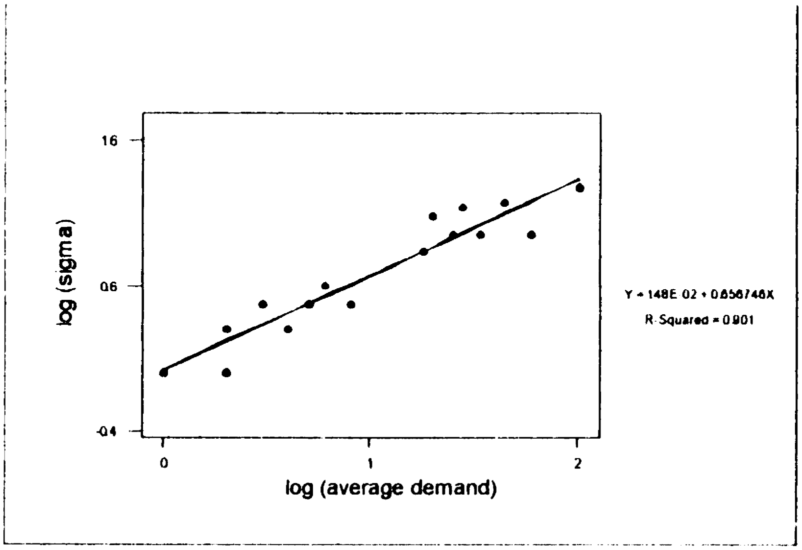
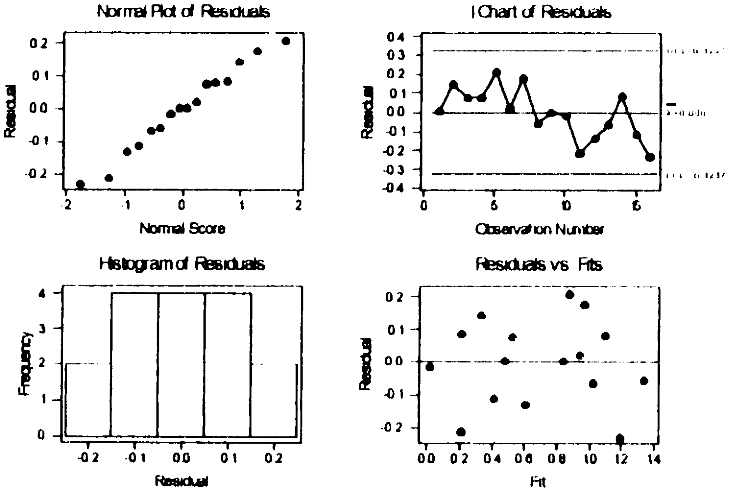


Figure 6.4-2: Residual Diagnostics for Forecast Error Regression

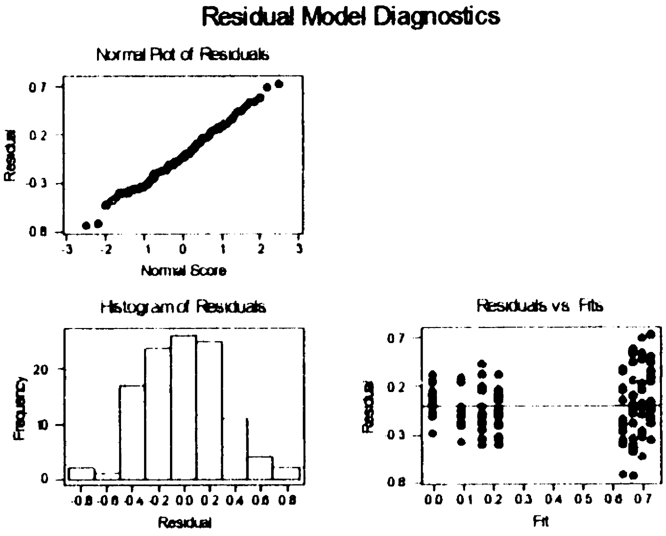


As one can see from the scatterplot, the R^2 statistic, and the residual diagnostics, the regression equation seems to be a valid model of forecast error standard deviation.

6.5. *S.K.U. Complexity for the Entire Fascia Process*

TOTALS	Super Coupe LH Cladding	Super Coupe RH Cladding	Super Coupe LH Rear Spat	Super Coupe RH Rear Spat	Super Coupe LH Front Spat	Super Coupe RH Front Spat	T-Bird Super Coupe Rears	Mustang US LH Rocker Cap	Mustang US RH Rocker Cap	Mustang LH Rocker Panel	Mustang RH Rocker Panel	Mustang Front	Cobra Front	Sable Rear Stone Deflector	Sable Front Stone Deflector	Cougar Fronts	T-Bird Fronts	Explorer Fronts	Continental Rears	Continental Fronts	Towncar Rears	Towncar Fronts	Mark VIII Rears	Mark VIII Fronts	Paint System Parts	
5								X	X	X	X	X													Chrome Yellow	Single-Tone Colors
6																			X	X	X	X	X	X	Ivory	
10														X	X	X	X		X	X	X	X	X	X	Pumice	
11	X	X	X	X	X	X	X							X	X	X	X								Electric Currant Red	
5								X	X	X	X	X													Performance Red	
6								X	X	X	X	X	X												Vermillion Tint	
5								X	X	X	X	X													Laser Red Tint	
2														X	X										Midnight Red	
6																			X	X	X	X	X	X	Electric Currant Tint	
6																			X	X	X	X	X	X	Berry	
2																X	X								Red Nightmist	
11	X	X	X	X	X	X	X							X	X	X	X								Royal Blue	
5								X	X	X	X	X													Bright Lapis	
6																			X	X	X	X	X	X	Dark Portofino Blue	
6																			X	X	X	X	X	X	Portofino Blue	
2														X	X										Indigo Blue	
2														X	X										Midnight Teal	
5								X	X	X	X	X													Bright Sapphire	
11	X	X	X	X	X	X	X									X	X						X	X	Venetian Blue	
5								X	X	X	X	X													Dark Tourmaline	
10														X	X	X	X		X	X	X	X	X	X	Deep Jewel Green	
4														X	X	X	X								Light Evergreen Frost	
6																			X	X	X	X	X	X	Evergreen Frost	
5								X	X	X	X	X													Teal	
6																			X	X	X	X	X	X	Medium Willow	
21	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X		X	X	X	X	X	X	Ebony	
5								X	X	X	X	X													Opal Frost	
6								X	X	X	X	X	X												Ultra White	
10														X	X	X	X		X	X	X	X	X	X	Performance White	
9	X	X	X	X	X	X	X									X	X								Performance White Tri coat	
10														X	X	X	X		X	X	X	X	X	X	Silver Frost	
6																			X	X	X	X	X	X	Medium Graphite	
9	X	X	X	X	X	X	X									X	X								Graphite Nightmist	
2																					X	X			Portofino Blue / Dark Portofino Blue	Two-Tone Colors
2																					X	X			Dark Portofino Blue / Dark Portifino Blu	
2																					X	X			Performance White / Medium Graphite	
2																					X	X			Ebony / Medium Graphite	
2																					X	X			Electric Currant Tint / Medium Graphite	
2																					X	X			Silver Frost / Medium Graphite	
2																					X	X			Medium Graphite / Medium Graphite	
1																		X							Berry / Champagne	
1																		X							Ebony / Graphite	
1																		X							Ox-white / Silver	
1																		X							Evergreen Frost	
242	6	6	6	6	6	6	6	11	11	11	11	11	3	10	10	12	12	4	13	13	20	20	14	14	TOTALS	

6.6. Sample of Residual Analysis for Mark VIII Fascia Model



This analysis of the data was done using Minitab®. The graphs are important in showing the reasonable assumption that the residuals are a normally distributed and that there is essentially a random spread of the residuals against the fitted values. There is more of a spread of the residuals in the lead times greater than five, but once again, for approximation, the model seems like a good one.

6.7. Inventory Carrying Cost

The annual inventory carrying cost (I)[3] used was 14.28% which was broken down as follows:

Table 6.7-1: Annual Inventory Holding Cost as % of Unit Cost

Cost	Percentage
Cost of funds	8.28
Obsolescence and Deterioration	3.00
Storage and Handling	2.00
Insurance and Taxes	1.00
TOTAL (I)	**14.28**

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[3] There are several different factors which can be used for the calculation of I. The cost factors used here were obtained from the Finance Department at Utica. For further information on the calculation of inventory holding costs see Renden, Quantitative Analysis for Management.

6.8. ILVS Calculations

Although the details of precisely how Ford plans to accomplish a 98% accurate 5-day fixed sequence are proprietary, I will point out some important factors. First, from Utica's standpoint, the successful implementation of ILVS implies that the sequence is correct >= 98% of the time. At the time this thesis was written, ILVS had not yet reached this successful stage. The ILVS analysis presented in sections 2.2.3 and 3.2.3, however, are written in the frame of mind "What if ILVS were successful?"

Second, assuming that ILVS is successful, safety stock calculations would still be based on normal approximations for the forecasts errors over the next five periods. Being >= 98% over a 5 day period implies that the sequence, and therefore forecasted demand for each s.k.u., is much more accurate. Evidence for this exists in the difference in forecast error standard deviation for the first five days (the "ILVS days") and the next five days in the fascia analysis section (section 3.2).

Although it is impossible to know what the individual s.k.u. forecast error distributions will look like in advance of successful ILVS implementation, in aggregate, the actual demand for all of the s.k.u.'s of an assembly line[4] should be no greater than 2% above the forecasts over a 5 day period. There are four ways that a car can be out of sequence over a 5 day period -- a car comes earlier or later in the sequence, a car is forecasted to be in the sequence but is not built, and a car is not forecasted and is built. The later reason could potentially result in an off-line due to demand being greater than the forecast. Assuming that all 2% of cars out of sequence are a result of this worst situation justifies the statement that actual demand for an aggregate of assembly line s.k.u.'s will not be greater than 2% of the forecasts over a 5 day period if ILVS met its goal. The worst case for a day of production would be that the forecasts are 100% accurate for 4 days, and only 90% accurate for the other day (this would still imply 98% accuracy over the 5 days).

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[4] This refers to all the s.k.u.'s for an automobile assembly line. For example, all Mark VIII front fascias are on the same Wixom assembly line. Continental front and Towncar front fascias **together** are the s.k.u.'s of an assembly line since both car types are built on the same Wixom automobile assembly line.

Protecting for this worst case, and making the assumption that a safety stock of 10% of demand over the replenishment lead time for each s.k.u. would achieve a very high service level, I estimate safety stock levels for an ILVS system.[5] This should provide a reasonable estimate for the aggregate safety stock levels required in an ILVS system.

Finally, ILVS offers the advantage of an extended lead time (5 days) for JIT opportunities. For the two cases studied, broadcast JIT implementations allow for a lead time of hours, not days.

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[5] This assumption is a reasonable approximation, though not entirely valid. Over a family of 10 s.k.u.'s, a forecast could be 100% accurate for 9 s.k.u.'s and only 10% accurate for one s.k.u. The assumption, however, is assuming a random distribution of forecast error to each s.k.u. (i.e. each s.k.u. shares the same amount of forecast and sequence uncertainty).

7. ST44 1995 Process Simulation Notes

7.1. General ST44 Process

Table 7.1-1 summarizes the daily demand and forecast information used for the simulation. The simulation computed daily demand and forecast uncertainty based on a normal approximation with an average value and the standard deviations shown in the table.

Table 7.1-1: Daily Demand and Forecast Characteristics Used for Simulation

						Car Characteristics				
Car Line	Average Demand	Standard Deviation of Demand	Standard Deviation of Forecast Error	Left S.K.U.	Right S.K.U.	Type	Mirror	Window	Map Pocket	Color
1	13	5.86	5.58	1	1	LX	MM	MW		Ebony
2	36	14.35	10.90	2	2	LX	MM	MW		Opal
3	3	1.62	2.13	3	3	LX	MM	MW		Willow
4	18	7.81	6.91	4	1	LX	PM	MW		Ebony
5	40	15.75	11.68	5	2	LX	PM	MW		Opal
6	4	2.08	2.57	6	3	LX	PM	MW		Willow
7	41	16.09	11.87	7	4	LX	PM	PW	MP	Ebony
8	114	39.54	23.24	8	5	LX	PM	PW	MP	Opal
9	14	6.26	5.86	9	6	LX	PM	PW	MP	Willow
10	1	0.62	1.03	10	7	GT		MW		Ebony
11	1	0.62	1.03	11	8	GT		MW		Opal
12	1	0.62	1.03	12	9	GT		MW		Willow
13	5	2.53	2.98	13	7	GT	PM	MW		Ebony
14	6	2.97	3.36	14	8	GT	PM	MW		Opal
15	1	0.62	1.03	15	9	GT	PM	MW		Willow
16	38	15.05	11.29	16	10	GT		PW	MP	Ebony
17	32	12.94	10.09	17	11	GT		PW	MP	Opal
18	3	1.62	2.13	18	12	GT		PW	MP	Willow
19	11	5.06	5.00	19	13	GT	PM	PW	MP	Opal
20	9	4.24	4.38	20	14	GT	PM	PW	MP	Saddle

I gathered the data above for a period of three months for the 1994 model year and transformed this data into predicted 1995 model year data using the method shown in appendix 6.4 for the forecast error, and used a similar method to convert the demand data shown below. As stated earlier, the average demand data for the 1995 model year was available.

To obtain the standard deviation of demand using 1994 model year data, the relationship investigated was

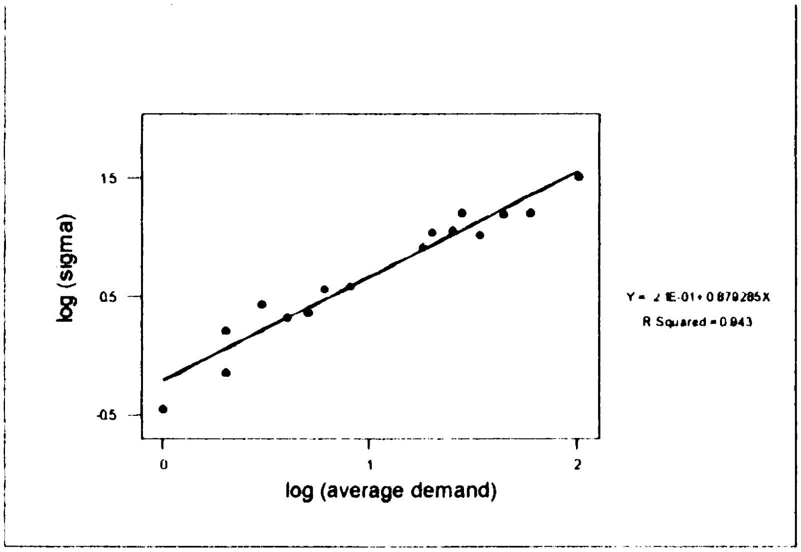
$$\sigma_D = A\bar{x}^c \qquad \textbf{Equation 7-1}$$

Where σ_D is the standard deviation of demand, $\bar{x}$ is the average demand of an s.k.u. and A and c are constants. Similarly, we have that

$$\log(\sigma_D) = \log(A) + c\log(\bar{x}) \qquad \textbf{Equation 7-2}$$

Linear regression produced the result shown in figure 7.1-1 which was used to calculate the standard deviation of demand data shown in table 7.1-1.

Figure 7.1-1: Demand Standard Deviation Vs. Average Demand



The process timings assumed for ST44 are shown in table 7.1-2 below. These numbers correspond to the production standards set for ST44.

Table 7.1-2: ST44 Process Timings

Process	**Standard Timings**
Monorail (set at rate to supply vacuum-forming machine as needed)	0.8 minutes / 2 panels

Vacuum-forming Machine (does a set of right and left panels at the same time)	0.8 minutes / 2 panels
Trimming Station (1 for right panels, 1 for left panels)	0.7 minutes / panel
Edgefold Station (2 for right panels, 2 for left panels)	1.3 minutes / panel
Punch Machine (1 for right panels, 1 for left panels)	0.71 minutes / panel
Heatstake Machine and Applying Options (1 for right panels, 1 for left panels)	0.71 minutes / panel
Weather Strip Station (1 for right panels, 1 for left panels)	0.35 minutes / panel
Inspection and Repair Station (1 for right panels, 1 for left panels)	average < 0.8 minutes / panel

The transportation time from Utica to CTI was assumed to be a constant 1.5 hours. The transportation time from CTI to AAI was assumed to be a constant 25 minutes.

Based on a month of data, the following average values were also used for the simulation:

Table 7.1-3: ST44 Line Performance

Category	Percentage of Output
Scrap	2.0
Downtime	3.2
Rework	13.1

Scrap and rework were generated explicitly in the simulation for the current production process. However, downtime was accounted for by allowing for excess capacity. In other words, the ST44 process had enough time to produce the daily demand requirement as well as some buffer time for downtime.

Finally, the following assumptions and process characteristics were used in the simulation:

- S.k.u.'s were produced and shipped in batches of 24.
- Raw materials were assumed to be available when needed.

- The monorail and adhesive spraying robots were set at the exact speed of the vacuum-forming machine.
- Downtime and scrap was done for the entire line. Scrap was taken out only at the end of the line, and downtime stopped production of the entire line.

7.2. ST44 JIT Process

The JIT simulation had the same characteristics as the general system except for the following changes:

- Instead of batch production throughout, there is batch production of 24 units up to the edgefolding process. After edgefolding the s.k.u.'s are pulled in sequence and shipped in sequence.
- After edgefolding, parts are pulled in sequence according to assembly plant demand.
- The production rate after edgefolding is reduced to the assembly line demand rate.
- Assembly line sequence demand is simulated using a random sample of the demand generated using the data in table 7.1-1.
- 8 buffers were added after edgefolding — four for right-hand panels with four colors and four for left hand panels with four colors.

8. Fascia 1995 Process Simulation Notes

8.1. General Fascia Process

Table 8.1-1 shows the daily demand and forecast information used for the simulation. The data was collected for two months. The forecast error column is the forecast error over a period. The yield is the first-run yield of the paint line assumed for the simulation. The standard deviation of demand is the variation observed from the average demand for each s.k.u. The average demand column is self-explanatory.

The paint system uses carriers, and the parts/carrier column indicates how many s.k.u.'s fit on a carrier. The paint required column gives the number of units scheduled for the paint line considering the yield. The even number of carriers column calculates the number of carriers required for the paint line rounded to the nearest even integer. It is a characteristic of the paint line to schedule the line with an even number of carriers.[1] The number of carriers column just shows the carriers which would be required if the paint line did not have the even carrier constraint.

The scheduled frequency column shows the how many days an s.k.u. is scheduled on the simulation. Due to paint line constraints it is impossible to paint every s.k.u. every day. The simulation (and current production system) accounts for this fact by scheduling parts at different frequencies. A scheduled frequency of 1 indicates that the s.k.u. is scheduled every day. A scheduled frequency of 2 indicates that the s.k.u. is scheduled every other day, etc.

Note that the replenishment lead time, L, used in the analysis sections is simply the scheduled frequency number plus 1. An additional day was added to give another day of "extra safety stock protection." Furthermore, the standard deviation of forecast error is the familiar σ_1, or the standard deviation of forecast error in a period, discussed in the analysis section as well. These numbers, plus the forecast error equations (equations 3-2 and 3-4) were used in the calculation of safety stock.

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[1] This has to do with the logic of the paint line control system. If a batch of s.k.u.'s are in uneven carriers, subsequent batches may get mixed up and thereby be painted incorrectly.

Table 8.1-1: Daily Demand and Forecast Characteristics Used

Part Description	Std. Dev. of Forecast Error	Std. Dev. of Demand	Average Demand	Yield	Paint Required	Parts / Carrier	Even # of Carriers	# of Carriers	Scheduled Frequency
MARK FRT BMPR IVORY	0 816	4 415	41	0 75	54	2	28	27	1
MARK FRT BMPR PUMICE	1 471	2 300	11	0 75	15	2	8	7	2
MARK FRT BMPR ELEC CRNT TINT	0 957	2 449	11	0 75	14	2	8	7	2
MARK FRT BMPR BERRY	0 929	1 968	5	0 75	7	2	4	4	2
MARK FRT BMPR DK PORTOFINO	1 147	1 155	4	0 75	5	2	4	2	3
MARK FRT BMPR PORTOFINO	1 125	0 535	2	0 75	2	2	2	1	4
MARK FRT BMPR VENETIAN BLUE	1 088	2 828	5	0 75	6	2	4	3	2
MARK FRT BMPR DP JEW GRN	0 655	2 343	12	0 75	16	2	8	8	2
MARK FRT BMPR EVERGREEN	0 894	0 934	2	0 75	2	2	2	1	4
MARK FRT BMPR MED WILLOW	1 366	3 027	13	0 75	17	2	10	9	2
MARK FRT BMPR EBONY	3 351	3 328	27	0 75	36	2	20	18	1
MARK FRT BMPR PERF WHITE	1 291	3 562	14	0 75	19	2	10	10	2
MARK FRT BMPR SILVER FROST	2 463	1 859	9	0 75	12	2	8	6	2
MARK FRT BMPR MED GRAPHITE	1 746	1 789	5	0 75	6	2	4	3	2
TOTALS			160				120	107	
CONT FRT BMPR IVORY	6 040	23 163	60	0 75	80	2	40	40	1
CONT FRT BMPR PUMICE	4 813	8 150	37	0 75	49	2	26	25	2
CONT FRT BMPR ELEC CURR TINT	4 000	2 290	17	0 75	22	2	12	11	2
CONT FRT BMPR BERRY	2 942	2 746	14	0 75	18	2	10	9	2
CONT FRT BMPR DK PORTOFINO	2 812	2 153	14	0 75	18	2	10	9	2
CONT FRT BMPR PORTOFINO	2 206	2 774	7	0 75	9	2	6	5	2
CONT FRT BMPR DP JEWEL GREEN	4 345	4 522	30	0 75	40	2	22	20	2
CONT FRT BMPR EVERGRN FRST	1 820	2 065	7	0 75	9	2	6	4	2
CONT FRT BMPR MED WILLOW	5 029	8 512	40	0 75	53	2	28	27	2
CONT FRT BMPR EBONY	5 029	7 851	39	0 75	52	2	28	26	2
CONT FRT BMPR PERF WHITE	4 427	5 836	33	0 75	45	2	24	22	2
CONT FRT BMPR SILVER FROST	4 507	5 696	33	0 75	44	2	24	22	2
CONT FRT BMPR MED GRAPHITE	3 066	1 975	14	0 75	18	2	10	9	2
TOTALS			344				246	229	
T/C FRT BMPR IVORY	3 722	14 997	36	0 75	48	2	24	24	2
T/C FRT BMPR PUMICE	3 246	8 574	43	0 75	57	2	30	29	2
T/C FRT BMPR ELEC CURRANT TINT	4 880	9 209	37	0 75	49	2	26	25	2
T/C FRT BMPR BERRY	2 337	7 445	15	0 75	21	2	12	10	2
T/C FRT BMPR DK PORTOFINO BLUE	2 626	6 978	19	0 75	26	2	14	13	2
T/C FRT BMPR PORTOFINO	2 732	7 228	12	0 75	16	2	10	8	2
T/C FRT BMPR DEEP JEWEL GREEN	3 492	4 924	22	0 75	30	2	16	15	2
T/C FRT BMPR EVERGREEN FROST	2 680	2 812	13	0 75	18	2	10	9	2
T/C FRT BMPR MED WILLOW	6 880	11 237	44	0 75	59	2	30	29	2
T/C FRT BMPR EBONY	3 327	9 808	34	0 75	45	2	24	23	2
T/C FRT BMPR PERFORMANCE WHITE	8 640	18 944	110	0 75	146	2	74	73	1
T/C FRT BMPR SILVER FROST	6 190	8 490	40	0 75	53	2	28	27	2
T/C FRT BMPR MED GRAPHITE	5 010	7 948	29	0 75	38	2	20	1[illegible]	2
T/C FRT BMPR PORT/DK PORTOFINO	1 047	0 516	2	0 75	3	2	2	1	4
T/C FRT BMPR DK PORT/DK PORTOFINO	2 073	1 506	3	0 75	4	2	4	2	4
T/C FRT BMPR PERF WHTE/MED GRAPH	2 839	1 288	5	0 75	7	2	4	4	4
T/C FRT BMPR EBONY/MED GRAPHITE	2 630	1 379	6	0 75	9	2	6	4	4
T/C FRT BMPR-ELEC CUR/M GRAPH*	1 949	4 010	9	0 75	13	2	8	6	4
T/C FRT BMPR SILVER FRST/M GRAPH	10 240	7 095	23	0 75	31	2	16	15	3
T/C FRT BMPR MED GRAPH/MED GRAPH	3 948	6 552	12	0 75	16	2	8	8	4
TOTALS			516				366	344	

Note that the Wixom Rears are not included in the table Once again, I assumed that the rears would experience the same production numbers.[2]

Even though the Wixom s.k.u.'s are the main focus of the thesis, the simulation and analysis does not ignore the other s.k.u.'s in the fascia process. For two weeks, similar data in table 8.1-1 was collected for all of the other fascia s.k.u.'s (complete list in appendix 6.5). An example of the such data is shown in the table below:

Table 8.1-2: Sample of Other Fascia Demand Characteristics

Part Description	Average Demand	Yield	Paint Required	Parts / Carrier	Even # of Carriers	# of Carriers	Scheduled Frequency
MUST FRT BMPR-CHROME YELLOW	23	0.75	30	2	16	15	2
MUST FRT BMPR-PERFORMANCE RED	11	0.75	14	2	8	7	3
MUST FRT BMPR-VERMILLION TINT C/C	107	0.75	142	2	72	71	1
MUST FRT BMPR-LASER RED TINT C/C	109	0.75	146	2	74	73	1
MUST FRT BMPR-BRIGHT LAPIS	39	0.75	52	2	28	26	2
MUST FRT BMPR-BRIGHT SAPPHIRE	17	0.75	23	2	12	11	2
MUST FRT BMPR-DK TOURMALINE C/C	125	0.75	167	2	84	83	1
MUST FRT BMPR-TEAL C/C	45	0.75	61	2	32	30	1
MUST FRT BMPR-EBONY C/C	113	0.75	151	2	76	75	1
MUST FRT BMPR-OPAL FROST C/C	40	0.75	53	2	28	27	2
MUST FRT BMPR-ULTRA WHITE C/C	118	0.75	157	2	80	79	1
TOTALS	748				510	499	
MUST COBRA FRT BMPR VERM TINT	24	0.75	32	2	16	16	2
MUST COBRA FRT BMPR EBONY	51	0.75	68	2	36	34	1
MUST COBRA FRT BMPR ULTRA WTE	27	0.75	36	2	20	18	2
TOTALS	102				72	68	

Note that both standard deviation columns (of demand and of forecast error) are missing in this table. Wixom fascias are the focus of analysis. I simply tried to load the fascia process with the typical demand experienced by the other s.k.u.'s and concentrated on daily variability in just the Wixom fascias.

Some process characteristics and assumptions included in the simulation were (see section 8.3 for further simulation details):

- A color change in the paint line created a gap of one carrier.

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[2] On average this would be expected. However, due to circumstances in which more front fascias are painted correctly than rear fascias, variation is experienced. Such variation is ignored here.

- All processes operated for 20 hours. Shift details were left out of the simulation.
- The throughput rate of the paint system was assumed to be 530 carriers in 2.5 hours.
- The postcure section of the paint system was assumed to take 70 minutes.
- Service parts were not scheduled.
- Downtime was not explicitly accounted for. Extra capacity was left on the processes to account for this as well as service parts, but overtime and weekend production could also be included if additional capacity was needed.
- A uniform random variable from 0 to 5 minutes was used as the setup time for the part changes on the assembly lines.
- Paint variability was simulated using a uniform random variable for the first-run yield centered around 0.75 which went from 0.65 to 0.85.
- A four hour set-up time was assumed for part changes on RIM machines. A 30 minute set-up time was assumed for the TPO machines.
- Coming off of the paint line, parts that need to be repainted are placed back into the pre-paint buffer ready to go into the next rotation. A fascia re-painted 3 times is scrapped.
- More detailed production constraints such as minimizing the emissions of volatile organic compounds due to paint line color changes and the constraints preventing one fascia color from following another in the paint system were not explicitly considered. The goal was to help determine aggregate inventory levels, as opposed to enumerating every detail for paint system operation.

8.2. JIT Fascia Process

The JIT simulation is very similar to the general simulation with the following exceptions:

- An additional assembly line was included which built Wixom fascias in sequence.
- Since the new line assembles only 6 different parts (Mark VIII, Continental, and Towncar front and rear fascias), I assumed that the set-up time for part changes could be reduced to zero.

- The rate of the assembly line was dictated by the demand from the Wixom assembly plant.
- Assembly line sequence demand is simulated using a random sample of the demand generated using the data in table 8.1-1.

8.3. More Simulation Details

The next few pages show tables of information used in the simulation and analysis sections for the fascia processes. Table 8.3-1 shows the assumed daily demand from the assembly plants for each of the fascia process parts (not s.k.u.'s). Although the total production numbers from an assembly plant remain relatively constant over extended periods, the mix of parts may change. For example, the mix of Towncars and Continentals on the Wixom assembly line changed three times during the six months I was at Utica. The percentage shown in the table is assumed here, but the reader should recognize the variation. Plant management, on the otherhand, can vary these percentages and perform similar analyses and simulations to make conclusions.

Table 8.3-2 shows the calculations conducted for scheduling the molding and trimming processes. The scrap percentages that were assumed are shown. The molding requirement (scrap accounted for) column simply means that molding scrap is left out of this number. The reason for this is that the simulation immediately requested another part to be produced when scrap was generated. Note that the right-hand (RH) and left-hand (LH) spats are combined into one part. This is due to the fact that both the RH and LH parts are produced simultaneously on the RIM machines. The presses column shows the presses I scheduled parts on.

Table 8.3-3 shows a summary of the paint system scheduling. The even number of carriers required column shows the carriers needed with the even paint system constraint and without consideration of color. The even number of carriers required (with color) column gives the number of carriers needed with the even paint system constraint and color considered. Note that for Mustang Fronts, 510 is in this column and in table 8.1-2. The totals at the bottom of the table give a rough idea of utilization numbers, but they do not include downtime numbers, color change gaps, etc.

Finally, table 8.3-4 shows specific variable and attribute parameters used in the Witness™ simulation created. This table shows the minutes per part standards used in the simulation for the various processes. For a few s.k.u.'s, the RIM machines mold more than one part per cycle. The minutes per part number is the cycle time divided by the number of parts per cycle.

Table 8.3-1: Assumed Daily Demand for Fascia Process Parts

Parts	Assembly Plant	Assembly Line Rate (Cars/Hr.)	% Car Type on Assembly Line	Daily Requirement (20 Hrs.)
Towncar Fronts	WI	43.0	60.00%	516
Towncar Rears	WI	43.0	60.00%	516
Continental Fronts	WI	43.0	40.00%	344
Continental Rears	WI	43.0	40.00%	344
Mark VIII Fronts	WI	8.0	100.00%	160
Mark VIII Rears	WI	8.0	100.00%	160
Explorer Fronts	LU	84.5	8.21%	139
	SL	50.0	8.50%	85
Explorer Fronts				224
T-Bird S/C Rears	LO	51.0	6.00%	61
T-Bird Fronts	LO	51.0	55.90%	570
Cougar Fronts	LO	51.0	38.10%	389
Sable Front Stone Deflector	AT	66.5	25.08%	334
	CH	66.5	25.08%	334
Sable Front Stone Deflector				667
Sable Rear Stone Deflector	AT	66.5	25.08%	334
	CH	66.5	25.08%	334
Sable Rear Stone Deflector				667
Mustang Front	DB	42.5	88.00%	748
Cobra Front	DB	42.5	12.00%	102
Mustang RH Rocker Panel	DB	42.5	88.00%	748
Mustang LH Rocker Panel	DB	42.5	88.00%	748
Mustang US RH Rocker Cap	DB	42.5	88.00%	748
Mustang US LH Rocker Cap	DB	42.5	88.00%	748
Super Coupe RH Front Spat	LO	51.0	6.00%	61
Super Coupe LH Front Spat	LO	51.0	6.00%	61
Super Coupe RH Rear Spat	LO	51.0	6.00%	61
Super Coupe LH Rear Spat	LO	51.0	6.00%	61
Super Coupe RH Cladding	LO	51.0	6.00%	61
Super Coupe LH Cladding	LO	51.0	6.00%	61

Table 8.3-2: Calculations for Molding Scheduling

		Scrap Percentages											
Parts	Daily Req. (20 Hrs.)	Assembly	Paint	Trimming	Molding	Total	Daily Req. With Scrap	Molding Standard (min / part)	Molding Hours Needed Daily	Presses Needed Daily (20 hours)	Molding Req. (Scrap Accouted For)	Presses	
RIM													
Towncar Fronts	516	2.0%	5.0%	1.0%	3.0%	11%	580	2.500	24.16	1.21	561	G1	G2
Towncar Rears	516	2.0%	5.0%	1.0%	3.0%	11%	580	2.553	24.67	1.23	561	G3	G4
Continental Fronts	344	2.0%	5.0%	1.0%	3.0%	11%	387	2.553	16.45	0.82	374	G5	
Continental Rears (RIM)	310	2.0%	5.0%	1.0%	3.0%	11%	348	2.553	14.80	0.74	337	G6	
Mark VIII Fronts	160	2.0%	5.0%	1.0%	3.0%	11%	180	2.609	7.82	0.39	174	G7	
Mark VIII Rears	160	2.0%	5.0%	1.0%	3.0%	11%	180	2.500	7.49	0.37	174	G7	
T-Bird S/C Rears	61	2.0%	5.0%	1.0%	3.0%	11%	69	2.400	2.75	0.14	67	G8	
T-Bird Fronts	570	2.0%	5.0%	1.0%	3.0%	11%	641	2.609	27.86	1.39	620	G8	G9
Cougar Fronts	389	2.0%	5.0%	1.0%	3.0%	11%	437	2.500	18.19	0.91	422	G10	
Sable Front Stone Deflector	667	2.0%	5.0%	1.0%	3.0%	11%	750	1.000	12.49	0.62	725	G11	
Sable Rear Stone Deflector	667	2.0%	5.0%	1.0%	3.0%	11%	750	1.046	13.07	0.65	725	F1	
Mustang Front	748	2.0%	5.0%	1.0%	3.0%	11%	840	2.500	35.02	1.75	813	F2	F3
Cobra Front	102	2.0%	5.0%	1.0%	3.0%	11%	115	2.500	4.78	0.24	111	F4	
Super Coupe RH Rear Spat	61												
Super Coupe LH Rear Spat	61												
	122	2.0%	5.0%	1.0%	3.0%	11%	138	1.237	2.84	0.14	133	F4	
Super Coupe RH Front Spat	61												
Super Coupe LH Front Spat	61												
	122	2.0%	5.0%	1.0%	3.0%	11%	138	0.727	1.67	0.08	133	F4	
TOTALS									214.04	10.70			
TPO													
Explorer Fronts	224	2.0%	5.0%		3.0%	10%	249	2.000	8.29	0.41	241	TPO1	
Continental Rears (TPO)	34	2.0%	5.0%		3.0%	10%	38	2.000	1.27	0.06	37	TPO1	
TOTALS									9.56	0.48			
Not Molded													
Mustang RH Rocker Panel	748												
Mustang LH Rocker Panel	748												
Mustang US RH Rocker Cap	748												
Mustang US LH Rocker Cap	748												
Super Coupe RH Cladding	61												
Super Coupe LH Cladding	61												

Table 8.3-3: Summary of Paint System Scheduling

Parts	Assembly Plant Daily Requirement (20 Hrs.)	Yield	Paint System Requirement	Parts / Carrier	Even # of Carriers Required	Even # of Carriers Required (with Color)	# of Carriers Required (with Color)
Towncar Fronts	516	0.75	688	2	344	366	344
Towncar Rears	516	0.75	688	2	344	366	344
Continental Fronts	344	0.75	459	2	230	246	229
Continental Rears	344	0.75	459	2	230	246	229
Mark VIII Fronts	160	0.75	213	2	108	120	107
Mark VIII Rears	160	0.75	213	2	108	120	107
Explorer Fronts	224	0.75	298	2	150	154	149
T-Bird S/C Rears	61	0.75	82	2	42	44	41
T-Bird Fronts	570	0.75	760	2	382	392	380
Cougar Fronts	389	0.75	513	2	260	270	259
Sable Front Stone Deflector	667	0.75	890	2	446	466	446
Sable Rear Stone Deflector	667	0.75	890	2	446	466	446
Mustang Front	748	0.75	997	2	500	510	499
Cobra Front	102	0.75	136	2	68	72	68
Mustang RH Rocker Panel	748	0.75	997	14	72	78	71
Mustang LH Rocker Panel	748	0.75	997	14	72	78	71
Mustang US RH Rocker Cap	748	0.75	997	14	72	86	71
Mustang US LH Rocker Cap	748	0.75	997	14	72	86	71
Super Coupe RH Front Spat	61	0.75	82	8	12	16	10
Super Coupe LH Front Spat	61	0.75	82	8	12	16	10
Super Coupe RH Rear Spat	61	0.75	82	8	12	16	10
Super Coupe LH Rear Spat	61	0.75	82	8	12	16	10
Super Coupe RH Cladding	61	0.75	82	8	12	16	10
Super Coupe LH Cladding	61	0.75	82	8	12	16	10
		Total Carriers Required			4018	4262	3992
		Carriers Per Revolution			530	530	530
		# of Revolutions Required			7.58	8.04	7.53
		Hours Per Revolution			2.50	2.50	2.50
		Hours Required			18.95	20.10	18.83

Table 8.3-4: Variable and Attribute Parameters for Simulation

Part	Stages of Production	Model Part Name	Part Number: attribute partNO	Molding Standard in min/part: variable ms	Trimming Standard in min/part: variable ts	Assembly Time in min/part: variable as	Parts per Carrier: function ppc	Molding Scrap Fraction: variable ms_f	Trimming Scrap Fraction: variable tscrp	By-rate through paint line: variable by_rt	Redo fraction for paint line: variable redo	Repair fraction for paint line: variable repar	Scrap % = (1 - by_rt - redo-repar)	Scrap fraction for post-paint repair: variable rpscrp	Assembly Scrap Fraction: variable asscrp
Regular RIM Parts															
Cont. Frt	M,T,P,A,S	contf	1	2.553	5.217	0.368	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Cont. Rr	M,T,P,A,S	contr	2	2.553	5.000	0.368	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Mark Frt	M,T,P,A,S	markf	3	2.609	5.217	0.500	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Mark Rr	M,T,P,A,S	markr	4	2.500	4.800	0.422	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Town Car Frt	M,T,P,A,S	tcf	5	2.500	5.455	0.368	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Town Car Rr	M,T,P,A,S	tcr	6	2.553	6.667	0.500	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Sable Frt. Stone Def	M,T,P,A,S	sfsd	7	1.000	5.455	0.368	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Sable Rr. Stone Def	M,T,P,A,S	srsd	8	1.146	6.667	0.500	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
T-Bird Frt	M,T,P,A,S	tbf	9	2.609	6.667	0.350	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Cougar Frt	M,T,P,A,S	cougf	10	2.500	5.455	0.267	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
T-Bird SC Rr	M,T,P,A,S	tbscr	11	2.400	5.000	0.428	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Mustang Frt	M,T,P,A,S	mustf	12	2.500	5.455	0.267	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Cobra Frt	M,T,P,A,S	cobf	13	2.500	5.455	0.267	2	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
T-Bird SC Frt. Spats	M,T,P,S	tbscsf	14	0.727	2.308	*0.000*	8	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
T-Bird SC Rr. Spats	M,T,P,S	tbscsr	15	1.237	0.739	*0.000*	8	0.030	0.010	0.750	0.150	0.050	0.050	0.030	0.020
Regular TPO Parts; function TPO(partNO)															
UN-105 Frt	M,P,A,S	un105f	16	2.000	*0.000*	0.500	2	0.030	*0.000*	0.750	0.150	0.050	0.050	0.030	0.020
Cont. Rr	M,P,A,S	ctpor	17	2.000	*0.000*	0.368	2	0.030	*0.000*	0.750	0.150	0.050	0.050	0.030	0.020
Painted but no RIM															
Mustang RH Rocker Pnl	P,S	mrrp	18	*0.000*	*0.000*	*0.000*	14	*0.000*	*0.000*	0.750	0.150	0.050	0.030	0.030	*0.000*
Mustang LH Rocker Pnl	P,S	mlrp	19	*0.000*	*0.000*	*0.000*	14	*0.000*	*0.000*	0.750	0.150	0.050	0.050	0.030	*0.000*
Mustang GS RH Rkr. Cap	P,S	mrrc	20	*0.000*	*0.000*	*0.000*	14	*0.000*	*0.000*	0.750	0.150	0.050	0.050	0.030	*0.000*
Mustang GS LH Rkr. Cap	P,S	mlrc	21	*0.000*	*0.000*	*0.000*	14	*0.000*	*0.000*	0.750	0.150	0.050	0.050	0.030	*0.000*
T-Bird SC Door Cladd RH	P,S	tbscdcr	22	*0.000*	*0.000*	*0.000*	8	*0.000*	*0.000*	0.750	0.150	0.050	0.050	0.030	*0.000*
T-Bird SC Door Cladd LH	P,S	tbscdcl	23	*0.000*	*0.000*	*0.000*	8	*0.000*	*0.000*	0.750	0.150	0.050	0.050	0.030	*0.000*

Key to Stages of Production

M - Molded	A - Assembled
T - Trimmed	S - Shipped
P - Painted	

Stages not used are italicized and outlined