Implementing a Demand Driven Production System in an Automotive Assembly Plant

by

Denise C. Johnson

B.S. Mechanical Engineering, Michigan State University, 1989

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

Master of Science in Management
and
Master of Science in Mechanical Engineering

at the
Massachusetts Institute of Technology
May 1997

Signature of Author
Sloan School of Management
Department of Mechanical Engineering

Certified by
Stanley Gershwin, Thesis Advisor
Senior Research Scientist, Department of Mechanical Engineering

Certified by
Donald Rosenfield, Thesis Advisor
Senior Lecturer, Sloan School of Management

Accepted by
Ain Sonin, Chairman
Committee on Graduate Students, Mechanical Engineering

Accepted by
Jeffrey A. Barks, Associate Dean
Sloan Master's and Bachelor's Programs

Implementing a Demand Driven Production System in an Automotive Assembly Plant

by

Denise C. Johnson

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

Master of Science in Management and
Master of Science in Mechanical Engineering

Abstract

Automobile manufacturers worldwide have begun to experiment with a variety of demand driven production systems. These automakers seek to produce vehicles that customers truly desire and deliver these vehicles to customers as quickly as possible. Demand driven manufacturers recognize the need to develop flexibility-biased competencies so that they can reduce supply chain costs while simultaneously providing a higher-than-ever level of customer service. Many automobile manufacturers have chosen to implement make-to-order, quick delivery, and/or distribution pooling programs in their pursuits to become truly demand driven.

Successfully implementing a demand driven production system in an automotive assembly plant requires both technical and organizational effort. Rather dramatic changes must be made to business processes, incentive systems, and work skill-sets. Strong leadership support combined with bottom-up worker involvement and an empowered implementation team are critical pieces to an effective system implementation strategy. Furthermore, as demonstrated through a computer simulation, the manufacturing system must have the ability to dynamically adjust to meet changing customer needs. To this end, assembly plants must strive to eliminate build constraints while maintaining simple, flexible decision rules to determine build priorities and to manage resources effectively.

The decision to implement a demand driven production system reflects a shift in manufacturing strategy toward flexibility and customer service. While the challenges involved with a successful demand driven system implementation are considerable, the potential benefits for customers, suppliers, and manufacturers are likewise significant. How well automotive manufacturers can succeed in integrating demand driven principles into the functional and organizational fabric of their companies may well ultimately determine the sustainability of the demand driven production systems long term.

Thesis Advisors:
Donald Rosenfield, Senior Lecturer, Sloan School of Management
Stanley Gershwin, Senior Research Scientist, Department of Mechanical Engineering

Acknowledgments

First, I wish to thank my husband, Jerry, for his limitless support and patience throughout the project. I also wish to thank my three daughters, Jessica, Sarah, and Katherine, for helping me to maintain perspective as my "group of words" slowly developed into a thesis. I am also grateful to my parents, Edward and Connie Mallek, for their constant encouragement and support throughout my academic and professional career.

Thanks must be extended as well to the many people who assisted my research. First, I thank my mentor, Laura Seyfang, for her friendship and guidance over the past two years. I also wish to express my sincere appreciation to the individuals from the company research site who directly assisted me with this project, including those from Research and Development, Assembly Operations, Production Control, Overseas Operations, and the Implementation Team.

At MIT, I wish to recognize my thesis advisors Don Rosenfield and Stan Gershwin. I thank each of them for their guidance and advice. I especially wish to thank Don for his helpful suggestions in the revision of this text.

Finally, I gratefully acknowledge the support and resources made available to me through the Leaders for Manufacturing Program.

Table of Contents

List of Figures

List of Tables

Section 1
Introduction

The process of distributing automobiles in the United States has changed very little over the past seventy-five years. Automotive manufacturers mass produce vehicles and deliver them to independent franchised dealers, who in turn retail those vehicles to customers in much the same way as their fathers and grandfathers before them. Industry improvement focuses on incremental change, led by entrenched firms seeking to maintain the status quo. And yet, significant changes are indeed underway in the automotive marketplace, threatening to alter the nature, scope, and composition of the competitive arena. Many of these changes have been preempted by developments in computer and information technology, allowing direct access to real-time information and feedback. This, combined with a growing understanding of the existing system inefficiencies, costs, and customer dissatisfiers, has propelled the automobile industry forward to embrace a new format. Within the next ten years, a revolution in automotive sales and distribution may advance the industry toward a format better suited to satisfy the demands of all constituencies involved.

Automotive sales and distribution trends emerging in Europe, the United States, and Asia point toward an expanded industry focus. In addition to overcoming market barriers of safety, functionality, styling, high quality, and efficient manufacturing, the latest strategies expand the focus to consider total supply chain costs *while simultaneously* providing a higher-than-ever level of customer service. To this end, automakers have begun to experiment with a variety of demand driven production systems that attempt to break the tradeoff between cost and service. Like lean production systems, demand driven systems seek to reduce waste. They concentrate on minimizing finished goods inventories and associated costs by creating a manufacturing system fast and flexible enough to meet market demand. Demand driven production systems attempt to only manufacture vehicles that customers truly desire and deliver those vehicles to customers as quickly as possible. Although automakers cannot become demand driven overnight, they are already beginning to build competencies around flexibility through the use of make-to-order, quick delivery, and/or distribution pooling programs. How well these programs are integrated into the functional and organizational fabric of the company may well ultimately determine their success. This thesis explores the issues fundamental to successful implementation, from understanding the basic building blocks of a demand driven system to determining the key requirements for organizational management.

1.1 Research Goals

This research addresses the manufacturing implementation of a demand driven production system. At the time of this project, numerous automotive companies were piloting production systems that contained demand driven principles. The concepts discussed in this thesis are common to most demand driven systems being developed.

The author's research experiences are used as a springboard for expressing ideas about systems implementation. The thesis deals as much with how to approach strategic implementation as it does with the ideas underlying a new production philosophy. It is the author's belief that the key to a successful strategy is a carefully executed implementation plan. To this end, the goals for the research are fourfold:

1. Understand the nature of demand driven production systems.
2. Identify the implementation impact to automotive assembly operations.
3. Explore the organizational requirements for successful assembly plant implementation.
4. Using a simulation tool that models the demand driven scheduling environment, illustrate some of the factors that may limit order flow.

1.2 Thesis Scope

The scope of this research is primarily limited to the automotive industry, although the concepts could be easily applied to other industrial and commercial settings. A brief overview of the thesis contents follows:

Section 2: This section describes the interplay of industry factors leading automotive companies to adopt demand driven production systems. It also reviews a number of demand driven system approaches being employed in a variety of industry settings, both automotive and non-automotive. The goal of this section is to synthesize a number of demand driven approaches that are practiced at different companies into a set of common demand driven elements or themes.

Section 3: In order to implement and effectively carry out a demand driven production system, the mechanisms and interactions of the traditional production system must first be understood. This section focuses on the functional and organizational requirements needed for successful assembly plant implementation. Ultimately, this discussion highlights both key implementation challenges and identifies different organizational mechanisms that can be employed to promote successful execution of demand driven system activities.

Section 4: This section examines the demand driven scheduling environment with the use of a computer simulation tool. This section specifically explores production control's ability to schedule orders while contending with factors that limit order flow. This discussion highlights some of the key relationships and systemic limitations involved with scheduling in a demand driven environment.

Section 5: The conclusion summarizes the first four sections and highlights the demand driven system implementation recommendations.

1.3 Research Methods

Much of the background information presented in Section Two is the byproduct of information attained through literature surveys while the author worked as a research assistant for MIT's International Motor Vehicle Program in the Spring of 1996. Further background information was gathered through additional literature searches and from information supplied by key individuals located at the company research site.

A majority of research for Section Three and most information regarding implementation were gathered through the use of interviews, plant tours and meetings. Specifically, I interviewed individuals from Research and Development, Sales and Marketing, Production Control, Assembly Operations, Materials, and Support Services Groups. In total, over thirty interviews were conducted over a three month timeframe. Furthermore, I spent time at various assembly plants to observe one demand driven system in operation. I gained valuable insight into implementation concerns through discussion with the many individuals working to implement the program. I was able to observe lively multi-functional interaction and interplay from attending a variety of operation and system related meetings. Finally, I witnessed dealer concerns firsthand by attending a regional dealer meeting for this demand driven system's pilot introduction.

I spent the first three months of my internship working as a first line supervisor in an automotive assembly chassis plant. This experience provided me a valuable understanding of the issues surrounding automotive assembly line balance, vehicle sequence, and flexibility issues. This work experience was especially important in helping me formulate the causal loop diagram presented in Section Three and the discussion presented thereafter.

The discussion that follows represents the culmination of four months of field research conducted to understand and support the implementation efforts of one demand driven manufacturer. Hopefully, this research effort will provide some key insights that will assist manufacturers in formulating future manufacturing strategies.

Section 2
Demand Driven Production System Background

This section synthesizes demand driven methodologies. The section provides background into the industry factors influencing automakers to embrace demand driven production systems. Next, it reviews a variety of demand driven methodologies and systems, both automotive and non-automotive, under development or in operation. Finally, it summarizes the elements common to demand driven systems.

2.1 Industry Factors / Background

The influx of high quality, low cost foreign imports in the 1970s and 1980s forced U.S. and European automakers to focus on transforming their manufacturing organizations into "lean producers." The effort to become "lean" pushed many automakers to reduce raw goods inventory, improve productivity, and curtail manufacturing costs.[1] Many of these organizations achieved these improvements through the use of team work and problem solving activities. As such, lean manufacturers have effectively maximized the value contribution at each production stage. Now, in the late 1990s, with the production benefits of the "lean initiative" well documented and understood, automotive manufacturers are working to apply many of these lean manufacturing concepts to their entire organizations. These manufacturers see benefits in closely linking together all functional areas in order to create a market driven system that is flexible and responsive to customer desires - a production system that is truly *demand driven.*

---

[1] Womack, J.P., Jones, D.T., Roos, D. , The Machine That Changed The World, New York: Harper Perennial, 1991.

However, the idea of applying lean manufacturing concepts company-wide is not the only reason manufacturers are embracing demand driven ideals. This revolution is supported by a number of contributing industry factors. These factors help explain why demand driven systems are currently being developed in the automotive industry. While the list is not meant to be exclusive, it details five major industry contributors to the development of demand driven systems, including:

- Customer dissatisfaction
- Sales and distribution costs
- System inefficiencies
- Competitive pressures
- Technology Enablers

Each of these factors will be discussed in the subsections that follow.

2.1.1 Customer Dissatisfaction

Automotive customers are increasingly dissatisfied with the traditional retail format. According to research obtained in a 1994 Allison Fisher Recontact Study[2], automotive customers cite inadequate dealer inventory and long factory lead times as significant dissatisfiers in the automotive shopping process. Thirty-five percent of buyers report that their dealer does not have in stock the exact vehicle in which they are most interested and the buyers feel they have to make a compromise in some aspect of the vehicle they purchase. Twenty-one percent of buyers choose to switch dealers when they are unable to find the car they want in inventory. Another 11 percent of buyers completely switch to another vehicle make when they cannot find the vehicle they want at a dealership.

---

[2] "Cadillac Sets New Standard With National Rollout of Custom Xpress Delivery," PR Newswire, Financial News Section, February 5, 1997.

A similar research study of automotive retailing in the United Kingdom[3] indicates that 20 percent of customers do not even purchase a vehicle because either vehicle delivery takes too long or no vehicle match can be found. Of those individuals who do make a vehicle purchase, only 25 percent find the exact specifications they originally wanted and 40 percent take alternative paint, trim, or options. Another 15 percent accept other specification changes.

Forcing customers to compromise leaves many customers feeling frustrated and unsatisfied with their car buying experience. A University of Maryland Study cited in McKinsey Quarterly[4] indicates that consumers rank the enjoyment of visiting a dealership (for new car purchase or repair) as 4.6 on a 10 point scale. Visiting a dealership rates among consumers least pleasurable activities, behind grocery shopping, doing laundry, and a visiting to the dentist. All of this data points to weaknesses in the existing sales and distribution framework. Automakers are now recognizing that significant retail and operational changes must be made in order to address these customer satisfaction issues.

2.1.2 Sales and Distribution Costs

Sales and distribution activities make up thirty percent of the retail cost of an automobile.[5] These costs include all activities occurring to an automobile after it leaves the assembly plant, including advertising, dealer costs, logistics, promotions, and rebates as shown in Figure 2.1 below.

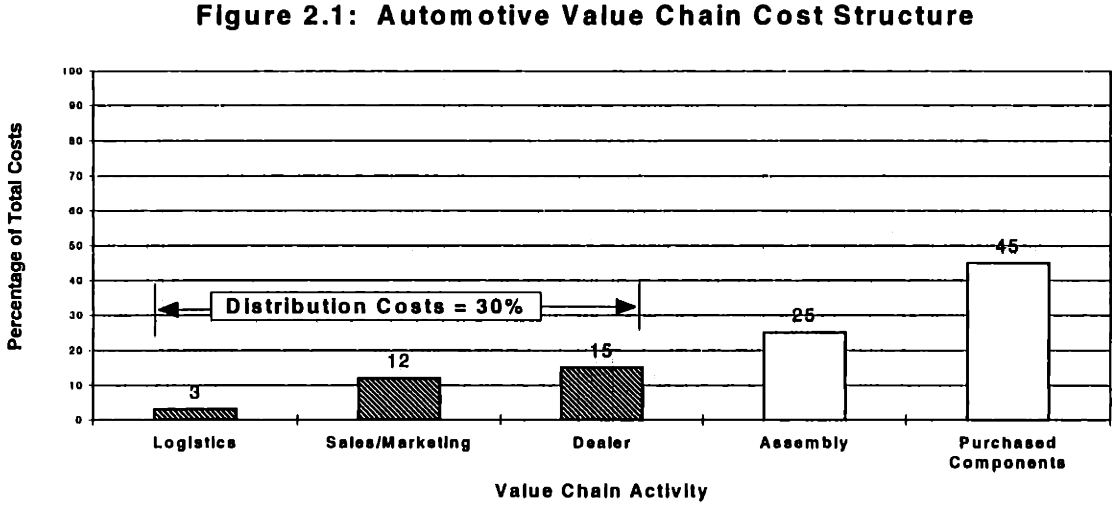
Included in the dealer and logistics costs are items such as delivery, stocking, security, maintenance, transfers, and interest. A major contributor to this cost is managing and holding finished goods inventory. The U.S. automotive industry average

---

[3] Harbour, M., Wade, P., Williams G., Brown, J., Jones, D., "Managing New Vehicle Supply and Demand in the 1990's," Harbour Wade/RMI, Soligull, UK, 1992.

[4] Mercer, G., "Don't Just Optimize - Unbundle," McKinsey Quarterly, Third Quarter, 1994.

[5] Ibid.



Source: McKinsey Quarterly, Third Quarter, 1994

Figure 2.1 Automotive Value Chain Cost Structure

days' supply of inventory runs at over 65 days, with 25% of inventory over 90 days old.[6] This inventory, waiting in dealership lots to be sold, is valued at over $36 billion. Once a vehicle held as inventory, however, the dealer must pay to hold and upkeep the vehicle. Inventory holding costs at a dealership range from $25 to $80 or more per vehicle per day.[7] Any transfer between dealers results in administration and delivery charges.

In addition to direct costs, sales and marketing consumed 12% of the total distribution costs. These costs include vehicle advertising, dealer advertising, sales, vehicle promotions/incentives, and dealer selling costs. Buried within all of these categories are those costs inherent in system operation, but hidden from traditional measurement. Jonathan Brown in his research paper "The Economics of the Car Distribution System[8]," identifies these "buried costs" as supply chain inefficiency costs that could be eliminated

---

[6] Wards Automotive Yearbook, Fifty-Eighth Edition, Southfield, MI, 1996.
[7] Phelan, M., "Stalking the Elusive 5-Day Car," Automotive Industries, November 1996,.
[8] Brown, J., "The Economics of the Car Distribution System," International Car Distribution Programme Ltd, Research Paper, November 1995.

or reduced in a make-to-order (or other demand driven) environment. Brown identifies four distribution inefficiency costs as follows:

- Stock holding costs: space, insurance, maintenance, interest costs etc.
- Stock clearance costs: over allowance on trade-ins, discounts
- Costs prompted by selling individuals non-ideal vehicles
- Loss of profit from inability to supply desired options/model/vehicle

2.1.3 System Inefficiencies

Although supply chain inefficiency from a cost perspective was discussed in the last section, the focus in this section is to understand the nature of the inefficiency from a system perspective. Traditional automotive sales and distribution methods are considered *push* in nature, because automobiles are produced from forecasts, rather than allowing customer demand to *pull* vehicles from the manufacturing process. While the push system has worked in the past for manufacturers, it contains mechanisms which disconnect the manufacturer from the market. The following example illustrates some of the inefficiencies with the push system:

Dealers' Perspective

On a weekly basis a dealer orders vehicles that he/she *perceives* will be in high demand and salable at his/her dealership when they arrive six to eight weeks after order. There are often many factors influencing his/her decision making. For instance, past weeks sales information and his/her gut feel about what will move in the future factor into the decision. The dealer must also consider the acquired sales allocation; that is, the number and kind of vehicles he is allowed to order. This allocation is based on the volume and velocity of his/her past dealership sales. Next, the dealer must check to see if the particular vehicle is available from the factory. Often manufacturing or material constraints limit the kind of vehicle available for order. Constrained vehicles models can be delayed in order queue for months before build. Finally, the dealer must consider requests from the manufacturer. Sometimes in exchange for those models most in demand, dealers are asked to accept unpopular, slow-moving models in hopes they will turn quickly. These factors, as well as others not mentioned, factor into the automobile ordering process at an average dealership.

Once the ordered vehicles arrive at the dealership six to eight weeks later, dealers have financial incentive to sell these vehicles quickly (see Sales and Distribution Costs section). Customers shopping at a dealership are strongly encouraged to purchase from dealer inventory rather than order direct from the factory. Often customers are asked to make compromises in their purchases when the products desired do not match with available vehicles. Compromise is often part of the bargaining process, where dealers dicker and deal with customers, discounting certain models, offering free options, etc., until the customer is satisfied with the package (vehicle for the price). The negotiation process attempts to optimize the satisfaction of the dealer and the customer, but is limited by the dynamics and structure of the existing system. With the dynamics of the decision making process so far removed from the manufacturer, understanding true customer demand becomes difficult. Instead, the manufacturer uses the available sales data - what automobiles actually sold - to prepare a forecast of future vehicle sales. The cycle becomes self-fulfilling: what is produced is sold; what is sold is produced.

The above example illustrates some of inefficiencies with the current push system of automotive distribution, including:

- System delays encourage dealer and manufacturer guessing.
- Existing inventory and selling strategies distort true market demand.
- Low communication and feedback among customer, dealer, and manufacturing constituencies exacerbates disconnectedness.

2.1.4 Competitive Pressure

As automakers battle for customers, each company searches for ways in which to gain competitive advantage over the other. In the area of quality and reliability, the gap between automakers is converging.[9] The average vehicle age has steadily increased since 1970, reaching 8.3 years in 1995.[10] Greater reliability has led to standard three-year / 36,000 mile warranties. Maintenance service intervals in many vehicles have moved to every 7,500 miles, with major adjustment periods extended to every 50,000 miles. Some automakers are moving toward maintenance-free steering and suspensions systems and 100,000 mile spark plugs.[11] While the Japanese automakers maintain the lead in quality, the once large performance gap has been substantially reduced. Automotive Executive[12] states, "On average, domestic and European products are now nearly equal to Japanese products in initial quality, and customer perception of quality differences has greatly diminished." While the 1996 Consumers Report[13] ranked Japanese produced vehicles number one in every vehicle segment except large cars, U.S. and European automakers consistently achieved favorable rankings in every vehicle segment.

With the convergence in quality and reliability understood, automakers are searching for new ways to distinguish themselves from one another. Demand driven production methods - with short order-to-delivery cycle time and the ability to deliver the exact car that a customer wants quickly - are considered competitive advantages, especially if the automaker can implement the strategy first in the market. Once the system proves successful, however, implementation becomes the cost of competing in the changing marketplace.

---

[9] Brown, J., "Customer Driven Delivery - International Implications," International Car Distribution Programme Ltd, Research Paper, January 1994.

[10] Automotive Facts and Figures, Automobile Manufacturers Association, Inc., Detroit, MI, Editions1939-1994.

[11] "The Future of the Retail Auto Industry," Automotive Executive, July 1993.

[12] Ibid.

[13] "1996 Cars Reliability", Consumers Report, April 1996.

2.1.5 Technology Enablers

In the automotive industry, the use of computers or other data gathering devices alone are not enough to enable the large scale systemic changes demand driven production systems will ultimately command. Instead, it is the task of "tying it all together "- using computers to gather key pieces of information and then using the information in management and decision making - that will enable demand driven production systems to ultimately succeed. The use of information technology and its application to supply chain management, logistics, and distribution continue to play important roles in the development of tools for managing demand driven systems. Computers permit manufacturers to electronically link multi-dimensionally - with dealers as well as suppliers. With the use of information technology, data previously unattainable or impossible to track can be quickly gathered, analyzed, and acted upon. Most significantly, the use of information technology facilitates new management practices that reduce and eliminate many of the traditional inefficiencies discussed in sections 2.1.1 through 2.1.4. Information technology creates a number of benefits[14] in general for retailing, including:

- *Faster transactions* - Instead of ordering in batches on a weekly basis, ordering is completed on a real-time, as needed basis. This reduces processing delays, miscommunications and mistakes. Faster transactions encourage rapid feedback of successes, complaints, and concerns.

- *Availability of more accurate information* - Computer systems can tell auto companies instantly what they are selling, how much money they are making on each sale, and who is buying the merchandise. With up-to-date information available, decisions can be made more quickly and accurately than ever before.
- *Closer control over supply chain* - With a physical link established in the supply chain, small changes are instantaneously communicated from dealer to manufacturer

---

[14] "Change at the Check out," The Economist, March 4, 1995.

to supplier. This facilitates a direct connection to customer demand at the same time forcing the associated risks to be more evenly shared across the supply chain.

- *Enables central process management, even when facilities are highly distributed (physical location)* - Information technology helps link parallel processes and functional organizations that are physically separated. It further improves decision making through heighten awareness of the "big picture" and increases cross-functional interaction.
- *Focuses the organization on performance outcome* - Information technology enables the development of new customer focused business processes that can be easily altered as customer needs change. It enables key process metrics to be actively monitored, easily collected, and widely / quickly distributed - may also improve employee accountability and sense of ownership.

In using information technology to manage the supply chain, auto companies can acquire more information about all aspects of their business. This allows them to manage each linkage as if it were unique while maintaining a system common to all.

2.2 Literature Review -Demand Driven Systems in the Automotive Industry

A literature review of automobile manufacturers reveals a wide variety of demand driven strategies emerging in Europe and the United States. Japanese automakers, while not taking an active role in introducing demand driven systems, have already implemented many of the developing strategies. This section reviews the development of these automakers from a geographic perspective; Europe, Japan, and the United States.

Europe

The recent trend toward reducing the level of stock at dealerships and holding it in a national or regional distribution center was pioneered by automobile manufacturers in the United Kingdom. Rover, one of the innovators of the concept, utilizes five regional distribution centers to stock all model lines. Only a restricted range of products are ordered for stock - the 20% of variants which represent 80% of volume. All other specifications are only available as build to custom order.[15] Rover claims to sell and dispatch 80% of the cars from its centers within three days.[16] Likewise, General Motors Europe developed its Custom Order Fulfillment system that uses regional distribution centers to stock "core products." The system allows average UK dealer stock to be reduced to 30 vehicles; special order delivery time is down from 12 weeks to 1 week for 60% of orders and 4 weeks for 80% of orders.[17] In a similar system developed by Nissan, called Strategy for Innovative Distribution (SID), a central stocking compound is located at Nissan's north-east England car plant. Nissan claims a dealer can *order any vehicle model with any specification* and have it delivered easily within 72 hours.[18]

In addition to leading the way with the use of central stocking, European manufacturers are pushing to reduce order-to-delivery lead-times. Ford has reduced U.K delivery time for a special order Fiestas from 45 to 15 days in a pilot conducted in 1996. Early this year, Ford will expand the plan to cover France, Italy, and Spain. Fifteen day order to delivery is a Ford 2000 goal.[19] Likewise, Volkswagen has started a pilot scheme in Germany to reduce lead-time to two weeks. The strategy is gradually being introduced as the group replaces each model, with the whole process to be in place in three years. VW plans to build vehicles only to specific customer orders for all VW Group brands to all countries in Europe.[20] Volvo, who began building 850s and 900s only to customer order a couple of years ago, will follow with the S40 and V40 models in the middle of next year. Volvo believes "buyers won't mind waiting for vehicles if the wait is as short as possible and the company sticks to a delivery date." Volvo would like to have the factory build almost all cars based on customer orders, leaving dealers with few or no automobiles on the dealer's lot. Volvo believes it can cut the delivery time to about three

---

[15] Wade, P., "New Vehicle Supply Systems," J.D. Power Roundtable, Boston, October, 1994.

[16] Taylor, A., "How To Buy a Car on the Internet," Fortune, March 4, 1996.

[17] Phelan, M., "Stalking the Elusive 5-Day Car."

[18] "Nissan Central Stock Cuts Lead Times," Automotive International, April 1994.

[19] Birch, S., "The Art of Taking Time Out," Automotive Manufacturing, April 1996.

[20] Huston, H., and Feast, H., "Lean Distribution to Cut VW Delivery Time," Automotive International, October 1996.

weeks by eliminating bottlenecks, studying new sea and overland routes, optimizing ship/rail/truck connections, and identifying faster ships.[21]

In a research paper[22] detailing European distribution strategies, Sander DeLeeuw, a researcher at Eindhoven University of Technology, summarized the major European developments in automotive distribution to include:

- Inventory centralization
- More efficient use of stock
- Shorter delivery lead-times
- Use of computer systems to integrate across all markets
- Reduce number of variant of each model range across Europe
- Focus on ensuring reliable delivery date

Japan

Japanese automakers have not been as active as the Europeans in implementing new distribution strategies. In some ways, Japanese automakers are ahead of their counterparts in eliminating waste from their production and distribution system. First, many Japanese automakers already have short order-to-delivery lead-times. Order to delivery lead-time at most Japanese automakers already averages under four weeks. A Toyota spokesman[23] claims, "Excluding regulatory impediments, we have the capability even now to complete the process, from order to delivery, in *under ten days* (emphasis added) - and without penalty of cost or quality, but no one's demanding that." Second, the number of model derivatives and options is already much lower for most Japanese producers. Japanese automakers have depended heavily on their export customer base. With the long shipment times involved with the export market, the automakers have

---

[21] Henry, J., "Volvo Wants to Speed Delivery, Cut Inventory," Automotive News, September 4, 1995.
[22] DeLeeuw, S., "Car Supply and Stocking Systems in Europe," International Car Distribution Programme, Research Paper No 10/95, July 1995.
[23] Phelan, "Stalking the Elusive 5-Day Car."

generally operated on a much simpler range of specification and options than local producers. Therefore, Japanese automakers do not have to deal with the issue of excess complexity like European and U.S. automakers[24].

While Japanese automakers may lead the industry with its lean practices, the Japanese environment itself poses unique challenges to the implementation of demand driven systems. The Japanese automotive buying process is laden with regulations.[25] Japanese customers must endure an inordinate amount of red tape before taking delivery of a vehicle. As a result, quick delivery systems would likely fail unless concurrent changes were made in buying procedures and regulatory factors. Furthermore, customer expectations differ in Japan. Japanese customers expect a much higher level of personal contact in automotive purchases and are largely passive when it comes to having to wait to obtain vehicles. The fact that 50% of vehicles are sold door-to-door and 10% are sold in the office reflects a very different retail structure in Japan than exists in Europe and the United States.[26]

For these reasons and also due to the high yen, Japanese automakers have chosen domestically to concentrate on productivity and cost rather than develop demand driven systems like their U.S. and European counterparts. For instance, Toyota's RAV4 Plant[27] in Toyota City has developed an overhead conveyor that is sub-divided into five parts with buffer zones in between to make the work less stressful. The plant focuses on using automation only in situations where it makes life easier for the workers. Experts believe the man-hours per vehicle in this plant could be as low as ten, which is over twice as efficient as conventional U.S. and European assembly plants. Because automation is minimal, the plant is both highly productive and highly flexible. This suggests Japanese automakers are perhaps best positioned to develop demand driven systems with their lean

---

[24] Wade, P., "New Vehicle Supply Systems."
[25] Phelan, "Stalking the Elusive 5-Day Car."
[26] Harbour, "Managing New Vehicle Supply and Demand in the 1990's."
[27] "The Kindergarten That Will Change the World," The Economist, March 4, 1995.

and flexible operations. So fart, however, these automakers have not yet seen the need domestically to change the retail / customer piece of the equation.

United States

U.S. automakers have chosen to implement demand driven systems with similar goals, but with varying methods. General Motors' system, Custom Xpress Delivery, went nationwide for all Cadillac models in March, 1997, and is being tested in various regions throughout the country on the Chevrolet Blazer / GMC Jimmy productline.[28] GM's strategy involves speeding up delivery time and improving vehicle availability by stocking popular vehicles in regional distribution centers. The popular vehicles are selected through analysis of regional and national sales information[29] and are said to represent approximately 70 percent of sales.[30] Dealers can then pull popular vehicles from the distribution centers for delivery within 24 hours after order.[31] If a customer desires a vehicle not stocked in the distribution center, General Motors will deliver a custom-built vehicle to the dealership within 19 days from order. For both popular and custom vehicles, customers receive a reliable delivery date commitment at the time the order is placed.[32] Under the GM program, Cadillac dealers pay a $285 fee for each car they receive, while Chevrolet Blazers and GMC Jimmys carry a $225 delivery fee.[33]

GM believes the strategy will provide dealers and customers access to a larger selection of inventory than could previously be stored in any one dealer's lot and will improve the chances for satisfying customer needs in a timely manner.[34] It will also allow dealers to reduce costs by holding less inventory than before. In addition to reducing costs and improving sales, GM hopes the Custom Xpress Delivery program will allow the company to save money by trimming the number of vehicle versions it makes.[35]

---

[28] Sawyers, A., "GMC Adds Regions to Delivery Test," Automotive News, March 17, 1997.
[29] "Cadillac Offers Faster Delivery," The Patriot Ledger, April 5, 1997.
[30] Connelly, M., "Ford Test Goal: 15 Days from Order to Delivery," Automotive News, July 29, 1996.
[31] Stern, G., "GM Expands Plan to Speed Cars to Buyers," The Wall Street Journal, October 21, 1996.
[32] "Cadillac Sets New Standard With National Rollout of Custom Xpress Delivery," February 5, 1997.
[33] Frame, P., and Child, C., "GM Dealers Will Lose Cash Bonus on Floorplan," Automotive News, December 9, 1996.
[34] Mateja, J., "Cadillac Aims to Deliver the Right Car, Right Away," Chicago Tribune, Business Section, August 12, 1996.
[35] Jedlicka, D., "GM Tests Speedier Delivery," Chicago Sun Times, Financial Section, October 28, 1996.

Other system benefits, as articulated by industry analyst Maryann Keller[36] include: "Parts production and vehicle assembly schedules would reflect true demand if the time were cut between orders and deliveries. Also, marketing costs would be lower – and dealers will carry lower stocks and trim expenses." GM has not disclosed if it will make the Custom Xpress Delivery program available to all its vehicle divisions.

Like GM, Volkswagen of America is piloting the use of distribution pools.[37] Dealers in Atlanta and Chicago areas can obtain VW Golfs and Jettas from regional distribution pools within 48 hours after order. VW expects the plan to help smaller dealers who cannot afford to stock a variety of colors and trim levels as well as metropolitan dealers who are faced with expensive real estate costs. As part of the strategy, VW uses information technology to connect its dealers to the inventory; dealers use computers to check regional inventories for customer matches and then tag vehicles as "sold" when a match is made. [38] Unlike GM dealers, VW dealers in the test areas pay nothing extra to obtain vehicles under the program.

Rather than distribution pooling, Ford Motor Company has chosen to implement a combination of lean production and lean distribution practices to achieve its goal of 15 day order-to-delivery lead time. Ford's strategy is currently being piloted on the Mustang in regions throughout the U.S. The program[39] uses order guides to help dealers order the models and options that customers desire. Ford believes if dealers order correctly, customers will find the vehicle he/she wants in dealer inventory. Furthermore, the program focuses on having dealers order vehicles earlier, allowing Ford to use the extra time to prepare assembly operations for the build. Under this program, dealers are asked to order vehicles 75 to 90 days in advance, and the order is locked in one-month prior to production. Dealers are then allowed flexibility for order amendment up to 10 days prior to production. Modifications are allowed on stand-alone options, like auto systems, interior trim items, and exterior color. Ford then permanently locks in dealer orders to

---

[36] Ibid.

[37] Sawyers, A., "VW: 48-Hour Delivery Looks Promising," Automotive News, February 10, 1997.

[38] Sawyers, A., "VW Dealers Like 48-Hour Order Plan," Automotive News, April 7, 1997.

[39] Connelly, "Ford Test Goal: 15 Days from Order to Delivery."

run its In Line Vehicle Sequencing (ILVS) system[40]. With this system, suppliers (of complex and highly proliferated parts) are provided the exact vehicle sequence 10 days ahead of production so that they can produce and ship exactly what is required. Suppliers then ship material into the assembly plant in exact production sequence. Ford says this process tells the suppliers exactly what is needed so they have no need to hold large inventories. Ford also dramatically reduces assembly plant part stock through the use of the ILVS system. Once the vehicles are produced, Ford will reduce the time it takes for delivery by as much as 33% by introducing a "hub-and spoke system," for sorting and delivery of vehicles.[41] The plan calls for a network ot four U.S. mixing centers that will allow vehicles to be sorted by destination and coordinated for final delivery by other railroads. Instead of shipping vehicles to 55 rail centers as was previously done, new vehicles are shipped to the mixing centers where rail cars are filled from multiple plants and are under way faster.[42] Each 50-100 acre mixing center will have flow-through tracks and an adjacent yard to receive and load dedicated unit trains. [43] Ford believes the system will substantially reduce the current 4 to 10 day vehicle dwell time associated with vehicle waiting in plant staging areas for shipment.

The details of Chrysler's demand driven efforts have not been explained in detail to the press. What is clear is that Chrysler has modified its custom ordering process and is looking to electronically link its dealerships to its vehicle assembly plants. Theodor Cunningham, executive vice president states that "The company has streamlined its ordering system to point where special orders of many models will be built and delivered in 16 days."[44] Furthermore, the company is looking to use its Trilogy system to allow customer spec their vehicles at the dealership and then real-time link the order to the assembly plant.[45]

---

[40] Birch, "The Art of Taking Time Out," .

[41] "NS and Ford Sign Innovative Agreement," Railway Age, November 1996.

[42] Connelly, M., "Ford Takes Steps to Chop Delivery Time to 15 Days," Automotive News, February 17, 1997.

[43] Taylor, "How to Buy a Car on The Internet."

[44] McKesson, M., "Chrysler Plans 16-Day Delivery," Lansing State Journal, January 10, 1995.

[45] Phelan, "Stalking the Elusive 5-Day Car."

2.3 *Literature Review - Demand Driven Systems in Other Industries*

A literature review of strategies employed in non-automotive industries reveals a collection of companies whose products, technological cycle-time, and distribution methods contrast significantly from one another. Nonetheless, each company has chosen to implement remarkably *similar strategies* in an attempt to satisfy customers and increase their own performance. The companies, Wal-Mart, Dell, Levi Strauss, and Case Corporation, are all employing demand driven principles. Vignette summaries of each company and their practices follow.

Wal-Mart

Wal-Mart[46] serves as the most notable example for the successful execution of a demand driven system. As one of the first firms to implement information technology as a means of altering the supplier-retailer relationship, Wal-Mart manages the supply chain to allow suppliers to produce to demand rather than to inventory. In the 1980s, Wal-Mart set up computer links between each of its stores and distribution warehouses in addition to linkages with each of the firm's main suppliers. With this system, Wal-Mart is able to manage just-in-time replenishment as well as anticipate sales patterns. Although the firm spent millions of dollars on the technology, Wal-Mart's distribution costs were under 3% of sales in 1992, compared with its competitors at 4.5 - 5% of sales.

Key to this strategy[47] is Wal-Mart's decision to do business only with vendors who invest in customized electronic-data-interchange technology and place bar codes on their products. Once the informational links are established, manufacturers then take primary responsibility for managing Wal-Mart's inventory. To enable manufacturers to make sound business decisions, Wal-Mart engages the supply base in intensive information sharing, joint planning, and substantial systems coordination. Wal-Mart's relationship

---

[46] "Change at the Check-out," The Economist, March 4, 1995.
[47] "Two Tough Companies Learn to Dance Together," Harvard Business Review, Nov./ Dec. 1996.

with Proctor and Gamble is often held up as illustration of this new kind of partnership. Proctor and Gamble receives continuous data from Wal-Mart by satellite on sales, inventory, and prices for products at individual stores. Proctor and Gamble then determines the quantity of goods required and automatically ships the orders - sometimes directly from the factory to the individual store. Invoicing and fund transferal are then completed electronically after the merchandise is sold to the end customer. So far the strategy has proved very successful for the firm. Wal-Mart successfully provides unprecedented levels of customer service at consistently lower prices than competitors by aligning the goals of the entire value-chain. These collaborative partnerships focus on reducing total costs, streamlining processes, focusing on customer requirements sales to thereby increase profits.

Dell

Direct sales computer manufacturer, Dell, embraces a flexible build-to-order strategy to achieve an order-to-delivery lead-time in the range of 2-3 days.[48] Like Wal-Mart, Dell's system[49] is closely linked to an information technology and close links with suppliers. Since Dell does not start ordering components or assembling computers until an order is booked, materials must be precisely managed to meet customer demand. Dell buffers material demand uncertainty by maintaining bulk components in warehouses located 15 minutes from factories. An outside logistics company is responsible for maintaining the warehouse and quickly transporting material to the factory by an as orders are booked. To enable flexibility and quick response from its supply base, Dell reduced the number of suppliers from 204 to 47, favoring regionally-based suppliers located in close proximity to Dell's factories. In the warehouse, suppliers are required to restock and manage their own inventories, and are only paid for components that leave

---

[48] "Selling PCs Like Bananas," The Economist, October 5, 1996.
[49] McWilliams, G., "Whirlwind on the Web," Business Week, April 7, 1997.

the warehouse. As a result, Dell's warehouses hold on average 13 days of sales versus the 25 days some competitors hold. Dell's strategy also is reflected in its organization, where operations-focused managers were recruited from companies like Motorola, Sun Microsystems, and Western Digital to implement change. The company added key performance measures - including reducing inventory and increasing return on capital - to encourage each of Dell's 10,350 employees to work together to make "big picture" decisions. The strategy has so far has proved successful; Dell maintains a 3 percent cost advantage over Compaq and a 6 percent cost advantage over indirect computer manufacturers. In 1996, Dell's sales jumped 71 percent while profits increased 91percent, reaching $518 million.

Levi Strauss

Clothing manufacturer Levi Strauss developed a demand driven system that allows customers to shop for an established variety of off-the-shelf jeans or, alternatively, have a customized pair of jeans manufactured in a Tennessee factory and delivered back to the store within two weeks[50]. Measurements taken at the store are sent through a modem to the factory where a dedicated sewing team constructs the jeans and then ships them direct to the store, via express mail. The jeans cost a customer about $15 more than an off-the-shelf pair. Levi's custom-fit program, called Personal Pair, was initiated in 1994 and is now available in any of the 30 Original Levi's Stores nationwide. Levis implemented Personal Pair as a piece of its strategy to focus on providing quick response to customers while minimizing the company's total costs[51]. Levi's strategy was facilitated through a $850 million information technology integration program that combined the company's Electronic Data Interchange System, LeviLink, with its account partnership program[52]. The integrated system ensures supplier requirements, order requirements, delivery

---

[50] "Fit To Be Tried and True," New York Times, April 6, 1997.
[51] Cooke, J.A., "Agility Counts!", Traffic Management, August, 1995.
[52] Nannery, M., "Levi's: Full Speed Ahead on Quick Response Drive", WWD, March 29, 1996.

requirements, and inventory levels are managed simultaneously for quick response and reduced waste. Levi's system attempts to meet the needs of its heterogeneous customer base while enabling the company to lower inventory levels through increased communication and rapid, continuous replenishment of goods.

Case Corporation

Case Corporation, one of the worlds largest manufacturers of tractors and construction equipment, sees room for worldwide growth if the company can implement a system containing demand driven principles. The company believes it will continue to grow only through a major restructuring of how it does business. To this end, the company wishes to simultaneously reduce cycle time from 3 months down to 1 month and dramatically cut its $2 billion finished goods and replacement parts inventory[53]. The effort, which is targeted for completion by the year 2000, includes many of the same operational changes Wal-Mart, Dell, and Levi Strauss have employed. The strategy begins by integrating the value chain through the use of information technology, allowing visibility into operations and practices worldwide. Furthermore, Case has chosen to completely outsource its logistics requirements to three suppliers worldwide.[54] The logistic suppliers, secured in 5-year contracts, will manage everything from domestic transportation to managing the flow of parts and components to and from Case warehouses and manufacturing centers. Furthermore, Case is negotiating with suppliers to encourage "consignment stocking", where suppliers are paid for goods when the parts are used on the assembly line, not upon delivery to the Case warehouse. The entire system is integrated and monitored through the use of performance measures, designed to encourage accountability and success.

---

[53] Marsh, P., "Focus on the Job in Hand: Case Study", Financial Times, London Edition, October 2, 1996.
[54] Bradley, P., "Triple Play; Case Corporation", Logistics Management, February 1997.

2.4 Common Elements of Demand Driven Production Systems

As the details of Sections 2.2 and 2.3 illustrate, companies often develop very different demand driven production systems, unique to their environment, competencies, and mission. However, at a strategic level, these unique systems share a set of common key elements that allow them to be grouped and classified as demand driven systems. These elements, while far from unique if considered individually, combine to create a very different environment for the manufacturer, distribution point, and customer. The elements include:

- Quick response order-to-delivery
- Significantly lower total finished goods inventory
- Direct communication and feedback link to customer demand via information technology
- Customer delivery date commitment; trend toward process and performance measurement
- Reduction in the number of item derivatives/complexity offerings
- Increased multi-functional integrated processes; closer alliances along value chain with increased risk sharing by suppliers; trend toward outsourcing of logistics/warehouse management

Section 3
Assembly Plant Impact

In the preceding sections, the principles and goals of demand driven production were reviewed. This section reviews the specific challenges facing an assembly plant poised to embrace a demand driven system. This section focuses on the functional and organizational requirements for successful assembly plant implementation.

3.1 Understanding the Nature of the Challenge

As reviewed in chapter 2, demand driven automakers seek to produce vehicles only in response to the pull of customer orders. Having committed to deliver an automobile to a customer by a specific date, demand driven manufacturers must invoke disciplined, yet flexible manufacturing processes. Information technology enables the manufacturer to make more informed, faster decisions than every before. Since demand driven production systems depend on highly integrated, multifunctional organizations, individuals must work together to minimize cost while maximizing customer satisfaction.

Without a doubt, the concepts and philosophy of demand driven production systems are easy to understand and to embrace. Yet the nature of the task - to completely revamp a production system and implement a new one - includes significant challenges. For demand driven automobile companies, the implementation of demand driven systems will impact a large numbers of assembly plants and employees. Change of this magnitude on the production floor and in the management offices will be especially difficult as the day-to-day pressures to maintain low costs and high efficiencies continue.

One of the primary challenges in implementing a demand driven system will be overcoming the interactions inherent in the traditional production system that limit the assembly plant from responding to customer demand. To explain this concept further, a diagram of the traditional production system is shown in figure 3.1 [55].

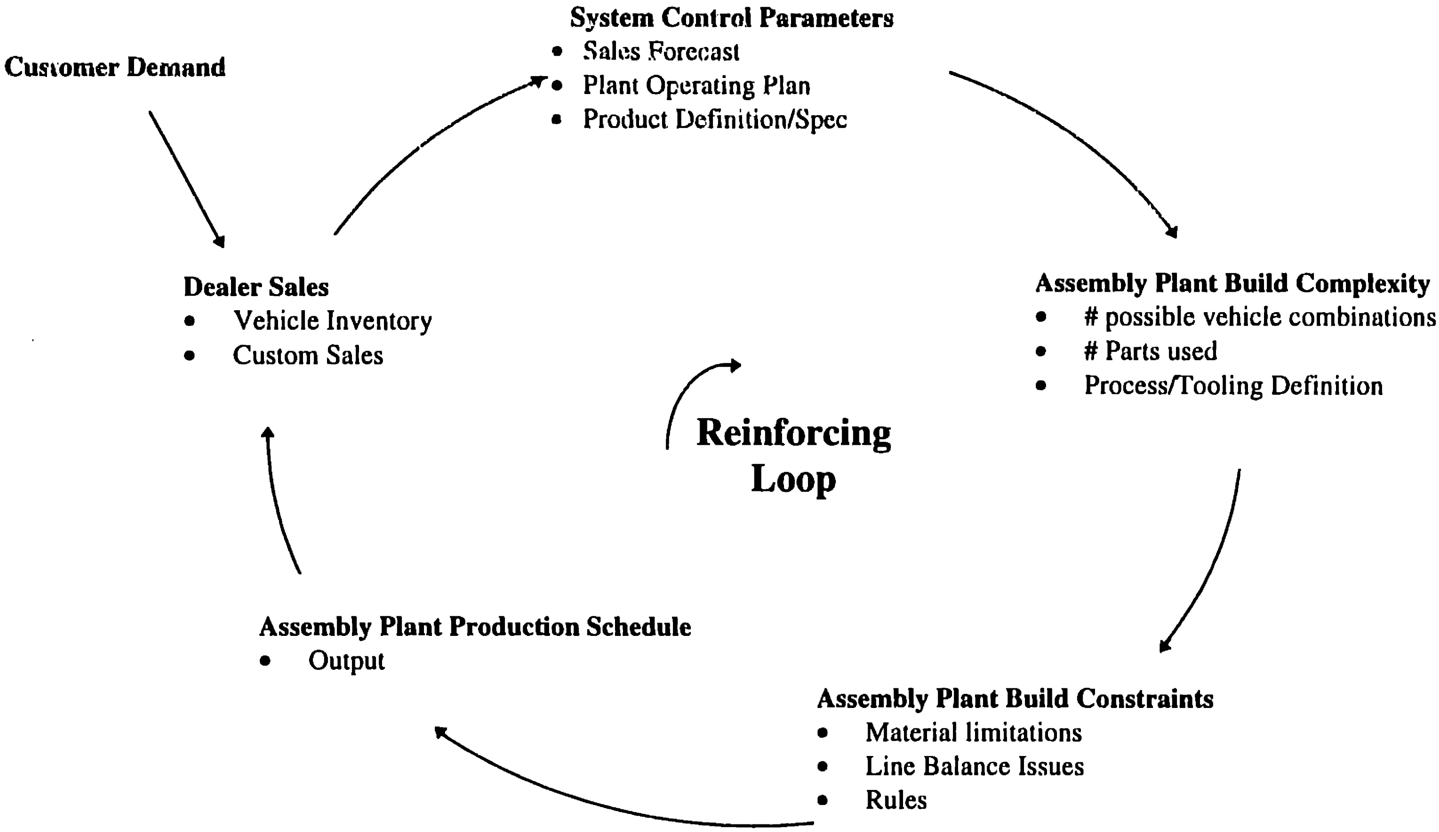


Figure 3.1 Causal Loop for Traditional Production System

The traditional production system is defined by a reinforcing causal loop. The loop begins as system control parameters are estimated through a sales forecast, assembly plant operating plan, and product definition / vehicle specifications. These parameters determine the amount of build complexity (# vehicle combinations, process tooling, etc.)

---

[55] See Senge, P.M., The Fifth Discipline, Currency/Doubleday, NY, 1990, for detailed discussion on causal loop diagrams

the assembly plant will encounter. The level of product and process complexity will, in turn, influence the build constraints / rules under which the plant operates. As complexity increases, the number of build constraints also increases. In turn, build constraints strongly influence the production schedule - what the assembly plant produces and when. The more numerous the build constraints, the more rigid the production schedule. Since the production schedule dictates the assembly plant's output, it also influences the kind and type of vehicles available for dealer sales. The reinforcing loop is closed as actual sales information is fed back into system control parameters, starting the causal loop over again. In short, the reinforcing loop implies that byproducts of the traditional production system (mix, model, constraints) tend to perpetuate themselves.

Two significant impacts result from the reinforcing loop. First, *each item operates not in isolation but in conjunction with others in the system.* For instance, assembly plant build constraints influence and affect dealer sales. Since dealers can only sell automobiles available to them, a limiting constraint (say a certain vehicle model) will force the dealer to push an available models rather that one constrained by the system. The other items interact in a similar manner. Second, *policies employed in the system continue to impact the system long-term.* While some items in the causal loop are adjusted or change frequently, others rarely change. Decisions made now impact the system now and continue to impact the system over time. For instance, prior to a new model introduction, body shop tooling is purchased and installed. By default this tooling regulates the mix between different models (i.e. flexibility) produced at the plant. Because considerable cost, time, and coordination is involved with implementing the tooling, it remains in place until the next model changeover regardless of market demand. The tooling design decision made with input from a sales forecast (system control parameter) continues to influence how, what kind, and when vehicles are built many years after implementation.

The impact of each decision followed by often significant delays in time serves to create an unresponsive production system which pushes vehicles into the market rather than responding to signals from customers. To this end, much of the discussion surrounding demand driven production systems revolves around finding ways to shorten the automobile order to delivery lead-time. The lead-time from automobile order-to-delivery averages six to eight weeks in the U.S. This lead-time consists of three primary activities: order processing, scheduling and production, and shipping, as shown in the Figure 3.2 below:

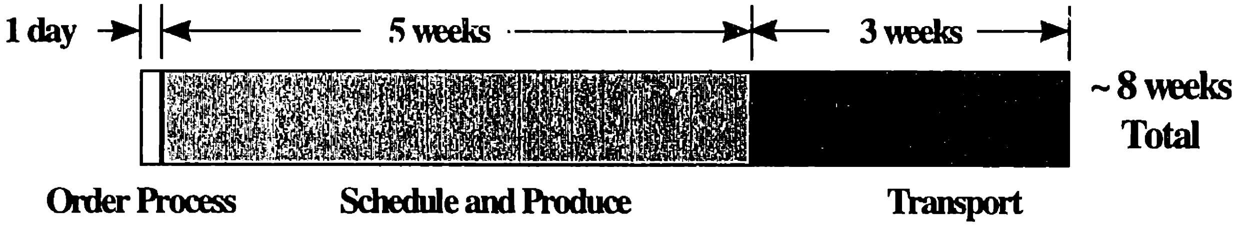


Figure 3.2 Traditional Production System Order-to-Delivery Lead-time

As Figure 3.2 illustrates, the lead-time to process an incoming order takes approximately 1 day. Scheduling the automobile for production and then assembling it requires about 5 weeks. Finally, transporting the automobile from the assembly plant to the dealership consumes approximately 3 weeks. Scheduling and production activities require the most processing time and are considered "bottlenecks" in the order-to-delivery process. It is not surprising, therefore, that much of the improvement activity has centered around understanding the underlying causes for this lead-time. Four such reasons include build complexity, assembly plant constraints, order pool size, and inherent production delays. These issues are explored in detail in the next subsections.

3.1.1 Product Design Build Complexity

Design build complexity in a very fundamental way contributes to order-to-delivery lead-time. If every automobile within a carline were identical and every assembly plant built only one unique carline, the scheduling and material ordering functions would be straightforward and trivial. In reality, however, assembly plants usually produce more than one - often up to five - vehicle models / body styles / carlines at one time. Within each model, there are a number of component options available for build. For instance, based on customer preference, three different engines may be selected for build: four cylinder, four cylinder high output, or six cylinder. To further complicate the build process, some options are tied to other options. Red interior, for example, may be ordered only in combination with a tan or red exterior color. Other options, like a CD player equipped radio, may be ordered *free-flow*, regardless of model or option content. Often Marketing Groups chose to combine specific component option combination into *merchandising models,* from which some option combinations are considered standard equipment while other options may continue to be free-flow. For instance, the 1997 Mustang GT Coupe is a specific merchandising model used at Ford Motor Company.[56] The standard equipment on this vehicle includes a 4.6L V8 engine, manual transmission, 16" aluminum wheels, P225/55ZRX16 tires, and cloth bucket seats. Optional content includes a choice of a number of free-flow options such as ABS brakes, power windows/doors/seats, keyless entry, compact disc player, body side moldings, speed control etc.

As the number of component options and models proliferates, the number of potential build combinations grows rapidly. Many assembly plants are faced with building, on average, only one or two identically outfitted vehicles in a given model year. For a medium volume assembly plant, that translates to 100,000 unique automobiles out of a model year population of 200,000 automobiles! Managing this complexity, especially in

---

[56] Ford Web Site, World Wide Web, URL http://www.fordvehicles.com/mustang/index.html, vehicle configurations, April 21, 1997.

the wake of changing demand, forces complexity into the scheduling and manufacturing processes at well.

3.1.2 Assembly Plant Constraints

Another major contributor to order-to-delivery lead-time is assembly plant constraints. Like a frame around a window, constraints define the limits of the assembly plant's operating envelope. Simply stated, constraints are the rules guiding the automobile production process. Constraints are multidimensional. They can be defined as either hard (i.e. cannot be violated under any circumstance) or soft (i.e. can be violated in some circumstances). Constraints range from global issues, like total plant capacity, physical floor space, and plant budget, to more local issues such as machine cycle time, supplier tooling capacity, and model mix flexibility. Constraints that impact scheduling and production functions can be classified into one of five categories[57] - allocation, planned constraints, supplier constraints, plant restriction and plant rules. The classification depends on the issue and factors limiting its removal. Table 3.1 details a matrix of these issues.

As Table 3.1 indicates, constraints are influenced by a variety of factors, ranging from assembly line balance to supplier quality concerns. The ability to eliminate constraints - on either a short or long term basis - depends largely on nature of the limiting factors. For example, suppose customer demand for an automobile continually exceeds assembly plant capacity. The assembly plant is capacity constrained. If one assumes demand constrains capacity by a substantial amount (>15%), then eliminating this constraint will likely require major changes to facilities, tooling, and workers - at a significant capital investment. The decision to expand capacity, therefore, is made only after intensive study and analysis.

---

[57] Note Allocation and Planned Constraints are normally part of the Assembly Plant Operating Plan. Since these parameters influence scheduling in the same way as the other assembly plant constraints, they are included for discussion purposes.

Table 3.1 Assembly Plant Constraints

Constraint	Examples	Limiting Factors
Allocation	Model Mix Max % of each model	Sales / Tooling
Planned Constraints	Daily volume Volume limit 1200/day	$, facility
Supplier Constraints	Constrained part Liftgate volume 500/day	$, technology
Plant Restrictions	No Spoiler Option until 6/98	Quality/Part Problem
Plant Rules	Spacing and Leveling Rules 1 trailer hitch every 4 cars	Line Balance

Assembly plant constraints impact the order-to-delivery lead-time by limiting the way in which customer orders are scheduled for production. In a traditional production system, customer orders are not processed FIFO. Instead of FIFO, a computer program fills the production schedule by selecting orders and arranging them in such a way to satisfy the assembly plant constraints. A limiting constraint can delay orders - queuing them for days, while those orders without the limiting constraint are scheduled and produced instead. Of course, in a traditional production system, the objective of the scheduling function is to serve the plant - not the customer. By leveling the load on the plant and creating a buildable schedule, the plant improves its likelihood of smooth, efficient, cost-effective operation. This reinforces the idea of continuous flow and maximization of output.

3.1.3 Order Pool Size

The size of the order pool directly contributes to the order-to-delivery lead-time. Most scheduling systems collect orders and place them in an order pool. Once in the pool, orders are sorted and sequenced before sending to the factory to be transformed into automobiles. The size of this order pool positively correlates with the time it takes to schedule and produce a vehicle, especially if one assumes that (in general) older orders are processed sooner than younger orders. As the order pool grows, the average length of time to process the order grows with it. Most traditional automotive production systems, by design, maintain three to six weeks worth of pooled orders, any number of which may be sorted and sequenced for build. Proponents of the traditional systems justify these large order pools based on their ability to create a smooth, efficient automobile manufacturing process. A large order pool accomplishes this in two ways. First, it allows the plant to select vehicle orders and sequence them in a way that satisfies the plant rules, constraints, allocation, etc. The larger the order pool, the easier it is to fill the schedule and sequence. With a large order pool, if one vehicle does not fit into the schedule because it violates a plant build rule, another vehicle - one that does not violate that rule - can be quickly found and inserted. (See section 3.2.2 for more details) A second reason for maintaining a large order pool has to do with raw material requirements. Auto manufacturers confirm material orders based on the completed order schedule. While these requirements are initially communicated based on a material forecast, as orders are scheduled and sequenced for production, the requirements are concretely known and communicated to suppliers. As the scheduled order bank grows, the automobile manufacturer can more confidently notify the supplier of the requirements in advance of production. This confidence allows the automobile manufacturer to hold less raw/part inventory in-house as a buffer against requirements changes.

Of course, these systems were designed with a very different goal in mind. Achieving a quick order-to-delivery response was not a primary objective of the traditional scheduling and production systems. Instead of focusing on a particular order flow process, the system worked to keep the assembly plant operations continuous and smooth.

3.1.4 Inherent Production Delays

While design complexity, plant rules, and order pool size contribute to the lead-time required to schedule an automobile, there are a variety of reasons automobiles are delayed in the production process as well. If automobiles were produced with perfect quality, on a First In First Out basis (FIFO), 24 hours a day, 7 days a week, then no production delays would exist. Traditionally, however, production delays occur in any one of four different categories:

1. Build Deviations/Defects
2. Production Interruptions
3. Special Procedures
4. "Normal" Production Delays

Build deviations/defect delays occur when a defect has been discovered on an automobile that cannot be corrected in process, and the automobile is removed from the production or shipping line. This can occur when an automobile is sent to a repair or set out area. It can also occur when a defect is so serious that the automobile must be scrapped. Scrapping necessitates a replacement vehicle be built by starting a new underbody at the beginning of the assembly process. Additionally, defect delays can occur after the automobile has been released for shipping, but a defect is discovered in route, such that the automobile is returned to the plant for repair.

Production interruptions occur more rarely than do build deviations / defect delays. Production delays often impact all vehicles contained within the build process. A labor strike is one example of a production interruption. More common production interruptions are caused by things like material shortages, equipment failures, or system failures.

Special Procedures are delays introduced by procedures or policies within the assembly plant. This would include activities such as Audit or Engineering Hold. A typical audit process pulls 5 automobiles per shift from the shipping line and holds these vehicles in an Audit area. The automobiles are thoroughly inspected (statically and often dynamically) for quality and/or build defects. Generally, within one to two days, the automobiles are returned for shipping. Similarly, if a vehicle is identified and tagged for Engineering Hold, it is delayed from shipment until the Engineer has completed his work on the vehicle. Vehicles are often placed on Engineering Hold for evaluation or observation reasons. As with an audit, automobiles are held only one to two days for Engineering Hold.

Normal Production Delays may occur frequently, depending upon how they are managed by the assembly plant. These delays include any planned downtime the plant experiences, such as breaks, weekends, holidays, summer shut-down, model change-over, etc. Some assembly plants, for instance, run almost non-stop (20 hours per day, 7 days per week), while other assembly plants operate two shifts (16 hours per day, 5 days per week). Except in special cases, all U.S. assembly plants delay production for holidays and summer shut down. Delays for model change-over can vary considerably, depending on the assembly plant and the degree of change / plant modification required. Delays for model change-over range from no delay to a number of weeks.

While production delays are considered a normal aspect of managing the assembly process, plant managers are constantly working to reduce and eliminate the most significant (and controllable) of these delays. For instance, recent efforts have been made to reduce *defect delays* by repairing vehicles in process, rather than in an end-of-line repair hole. This requires the use of a stop (or andon) cord to allow repairs to be made in station. Stopping the assembly line for a few seconds can reduce the quantity of vehicles delayed in repair by significant proportions. Furthermore, *normal production delays* have been reduced in capacity constrained assembly plants through the use of new workforce methods, such as 3 crew/2 shift. This workforce method effectively allows the plant to be utilized more fully, minimizing in-process delays caused by work stoppage on weekends and between shifts. Moreover, initiatives to eliminate model change-over delays serve to encourage managers to develop faster and more innovative ways to speed vehicles from production to delivery. In all these initiatives, the focus is to keep vehicles moving in an orderly flow through the process. Production delays are avoided by maintaining a rhythm or "production cadence" through which vehicles flow, without exception, from production to delivery.

3.2 Assembly Plant Implementation Issues

Implementation of a demand driven production system impacts the automotive assembly plant in a number of ways. This section first explores the strategic issues, and then discusses the functional and organization requirements for effective implementation.

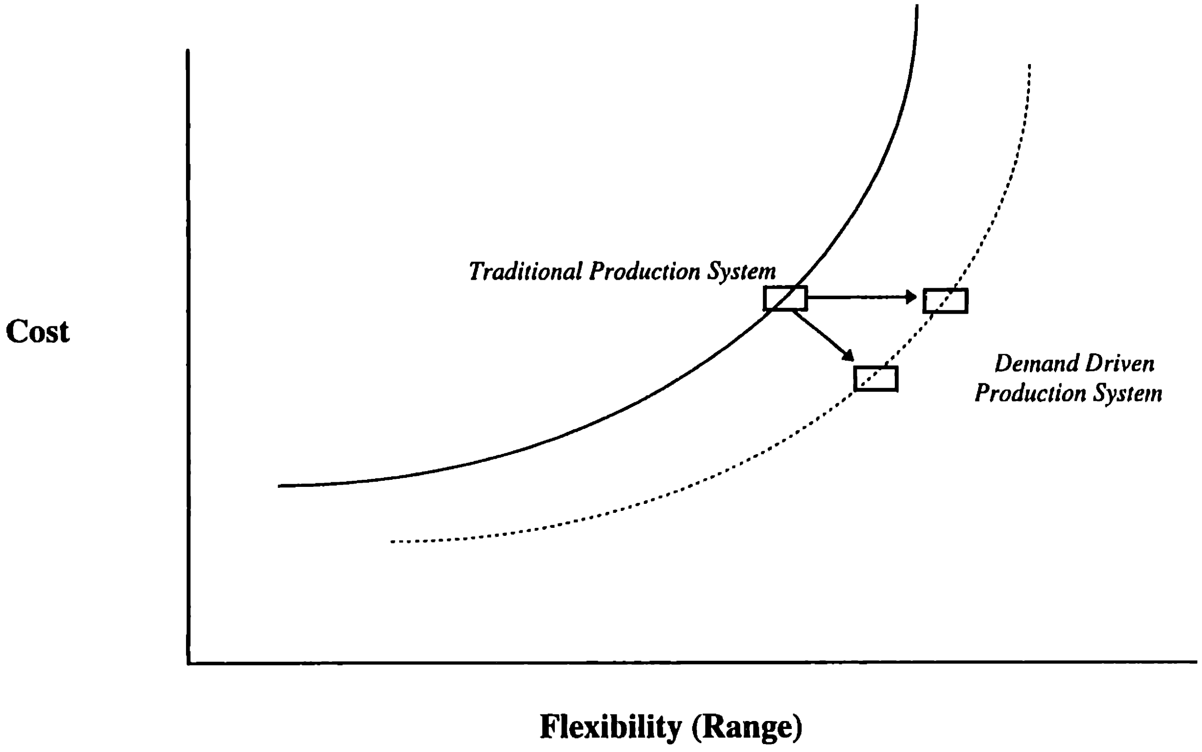
3.2.1 Strategy and Focus

At the present time, demand driven production systems do not invoke a radical break in manufacturing strategy. No new manufacturing technology or massive restructuring is introduced to change the way automobiles are assembled. Rather, demand driven automakers produce vehicles in much the same way as traditional manufacturers but institute changes along some key dimensions; they expand their mission toward developing and reinforcing internal capabilities in flexibility and service. To understand this concept more fully, it is useful to examine it through a manufacturing strategy framework developed by Robert Hayes and Gary Pisano of the Harvard Business School. Hayes and Pisano[58]in their article *Manufacturing Strategy: At the Intersection of Two Paradigm Shifts* suggest that manufacturing strategies include paths of learning or improvement trajectories. Deciding whether to move along a "current frontier" or transition to a "new frontier" depends on which capabilities a firm chooses to develop. Through strategic choices, firms can improve along more than one dimension at the same *time*, although not all performance dimensions can be improved at the same *rate*. Hayes and Pisano concede that critical tradeoffs are still required, but they are made through the "selection, development and exploitation of superior capabilities" rather than along static performance dimensions. This framework suggests that demand driven automakers who chose to develop a flexibility-biased trajectory must place greater emphasis on improving

---

[58] Hayes, R., and Pisano, G., "Manufacturing Strategy: At the Intersection of Two Paradigm Shifts," Production and Operations Management, Vol. 5, No. 1, Spring 1996.

flexibility through structural and infrastructural policies. Figure 4.1 provides a visual representation of movement of a demand driven flexibility-biased trajectory.



Adapted from Hayes and Pisano, "Manufacturing Strategy: At the Intersection of Two Paradigm Shifts"

Figure 3.3 Flexibility-Biased Trajectory

Figure 3.3 demonstrates a flexibility-biased trajectory. In transitioning from one path (a traditional production system) to another (demand driven system), the company is able to maintain or even lower its costs while at the same time improving flexibility. As capabilities are further refined, the company builds flexibility while actually lowering costs.

Flexibility

Flexibility may be thought of as the ability of the assembly plant to build a desired vehicle per unit time. An extremely flexible assembly plant could build any specified vehicle at any time. An inflexible plant could only build vehicles in pre-specified ways and would be unable to quickly adapt to changing inputs. In section 3.1, some of the factors limiting flexibility were discussed, including build complexity, work balance, tooling, and system dynamics. As automakers move toward demand driven production systems, building capabilities to improve flexibility allow automakers to respond immediately to changes in customer demand. Suggestions for building these capabilities in a demand driven assembly plant include:

- ***Limit Product Complexity***: eliminate unnecessary product variation; eliminate non-key configurations (Responsible: Marketing, Product Line Managers)
- ***Limit Process Complexity***: define simple, standard processes; purchase low cost flexible manufacturing tooling; reduce use of elaborate or complex equipment (Responsible: Manufacturing Engineering, Assembly Plant)
- ***Coordinate Product and Process Design to reduce impact to work / line balance***: design for common or similar process no matter the vehicle combination (Responsible: Product Engineering, Manufacturing Engineering, Assembly Plant)
- ***Reduce and/or Eliminate Constraints:*** eliminate bottlenecks and improve responsiveness by eliminating system constraints. (Responsible: Assembly Plant)
- ***Reduce Lead-times:*** reduce long lead-time events from events required for response to changes in customer demand by reducing lead-times: scheduling, components, etc. (Responsible: Process Ownership)
- ***Buffer:*** where product /process technology changes and lead-time reduction efforts are infeasbile, improve flexibility by strategically buffering weak links upstream - raw materials / parts, people. (Responsible: Assembly Plant)
- ***Employ Flexible Operating Policies and Procedures***: build-in ability to adjust policies and procedures as environment changes. (Responsible: Process Ownership)
- ***Create Flexible Value-Chain:*** Key components (long-lead) require development of critical suppliers capable of meeting demand driven needs. Enable through real-time information system link. (Responsible: Purchasing, Supplier Development, Plant Materials Group)

- ***Reduce the Number of Decision Points / Interaction Required in the Process:*** balance controls with need to streamline process. Reduce intervention points such as forced product-line allocation, model mix, option content. Allow demand to dictate priorities. (Responsible: Process Ownership)

The suggestions for building flexibility-biased capabilities in a demand driven assembly plant require ownership from functional areas outside of the assembly plant. Sales and Marketing, Product Line Management, Product Engineering, Manufacturing Engineering, are just a few of the functional players whose involvement plays a critical role in enabling the development of flexibility-biased capabilities. Many of the tasks identify a 'Process Ownership' responsibility. This may be interpreted as a system responsibility which spans over the entire demand driven process and will require multifunctional process ownership.

3.2.2 Functional Assembly Plant Issues

So far this paper has examined the implementation of a demand driven production System from a general, rather strategic perspective. It is also useful to understand, from an operational perspective, how demand driven systems impact assembly plant functional practices. The purpose here is not to explain *how* to implement these changes but to *examine the nature* of the practices and understand how they serve to build and nurture flexibility-biased capabilities. Table 3.2 compares the assembly plant functional environment in a traditional setting to one operating in a demand driven environment. As the table illustrates, a demand driven system impacts a wide variety of functional practices. In *production control*, the order sequencing frequency increases from a weekly cycle to one more frequent. Since orders are sequenced frequently, the size of the order pool size will be reduced. More frequent sequencing and smaller order pool serve to reduce the time that an order sits queued for production. Within the sequence, some

Table 3.2 Functional Comparison: Traditional Versus Demand Driven

Functional Area	Traditional	Demand Driven
Production Control	Weekly order sequencing ~2 week order pool No prioritization	Frequent order sequencing Smaller order pool Order prioritization
Materials Group	Lean / JIT part buffers Allow pre-sequencing of parts	Manage / increase part buffers for demand volatility and provide schedule visibility to suppliers Eliminate pre-sequencing activity or shorten sequenced order stream (i.e. ILVS)
Production Operations	No prioritization Ad Hoc and local procedures	Prioritize vehicles as required Expedite vehicles through the production process by minimizing delays through audit, repair, scrap restart, engineering hold, etc. Defined policies for handling build out, start-up, holidays, prod. delays
Logistics	Shipping responsibility	Increased role in managing inventory in addition to shipping responsibility
Systems / IT Support	Localized focus	Real-time information focus Common processes across plants Expanded role as linkage

orders may be prioritized over others. Highest priority vehicles would be bumped to the beginning of the queue so that they are less apt to be effected by downstream production delays.

The Production Control policies impact the assembly plant's *Materials Organization.* What happens to the material supply when the time between sequencing and production dramatically decreases? First, the reduction in order lead-time may prevent geographically dispersed suppliers from delivering components pre-sequenced for production. Pre-sequencing is generally used for bulky, highly proliferated parts to minimize part inventories, floor-space requirements, material handling, and operator workload. In a traditional production system, a 1 to 2 week sequenced order stream provides sufficient lead-time for suppliers to build to the ordered sequence. However, with a "just-in-time" order queue, there is often insufficient time to carry out this pre-sequencing activity. This forces the assembly plant to pursue alternate strategies - for instance kitting (combining individual components into kits), batching, or in-plant sequencing - to alleviate these concerns. For those plants using In Line Vehicle Sequencing (ILVS), it will be necessary to shorten the length of the sequence stream to only a few days in order to expedite orders for build.

A second potential impact of sequencing so close to production is the impact of *material requirements volatility.* That is, the material available in the plant may not cover what is needed for production. To deal with this, the plant can hold extra material in buffer to guard against changes in demand. This has a potentially negative impact of increasing assembly plant inventory costs, floor-space, material handling and such within the plant. It also serves counter to many of the lean production practices, which focus on reducing excess material inventory. A second, potentially better way to deal with this concern is to increase the supplier visibility to demand by creating a pull signal whenever stock falls below a certain level. With "lean" systems, material inventory levels / requirements are often calculated based on a number of factors including forecast usage, physical part size, travel time/distance, replenishment rate, etc. Target inventory levels are maintained based on the calculations, with suggestions for visual minimum and maximum included. Most important for demand driven material systems is for the inventory calculation to include a parameter for requirements volatility. As requirements volatility increases, more material must be held in inventory to buffer against the changing requirements. This practice succeeds in adding inventory only for only those parts whose demand requirements are volatile, while maintaining minimal levels for all others.

The third functional area impacted by demand driven production is *Production Operations.* To ensure delivery commitments are met, Production Operations concentrates on producing and shipping vehicles as quickly as possible. Vehicles to be expedited for shipment must be clearly identified. This identification is especially important for areas where vehicles can be delayed, such as repair, audit, body set-out, and the like. Business processes communicate common processes and instruct operators to service all priority vehicles before non-priority ones. Priority vehicles that become delayed must be tracked down and expedited for shipment.

Another impact to Production Operations is the use of management policies to handle "planned" production delays. For example, how the plant manages production ramp-up or model year build out changes with the implementation of demand driven system. The plant must ensure delivery date commitments are met in the midst of disruptions from steady state production. This requires the establishment of new management policies and best practices.

The fourth functional assembly plant area impacted is *Logistics.* Many automakers have expanded the role of the logistics provider to include responsibility for managing finished goods inventory. These providers must now ensure vehicles are delivered to the dealership in time to meet the commitment date established at order entry. The logistic provider's expanded role increases the interaction and coordination required between the provider and the assembly plant. This results in increases in information sharing, accountability, and communication.

The fifth and final assembly plant functional area impacted by a demand driven system is the *Systems Support Group.* This group provides the system tools and electronic support spanning the entire order-to-delivery cycle. Their role in identifying priority vehicles, tracking work-in-process and finished goods inventory, generating reports and the like, improves system management and allows the assembly plant to maintain a real-time information focus. Common processes are developed by the Systems Support Group to link the use of best practices across assembly plant and enable faster assembly piant ramp-ups.

3.2.3 Organizational Issues

The greatest challenges in implementing a demand driven system are neither technical nor structural. Indeed, the most formidable tasks are organizational and cultural. The successful execution of demand driven systems depends on the support of a company's leadership, the alignment of the measurement systems with desired performance, and the ability of the company to engage a workforce to work toward expanding flexibility-biased capabilities.

Leadership

As compared with other management functions, assembly plant managers have a great degree of independence and autonomy in setting the direction of change for their organizations. Many of these plant managers have successfully managed through the U.S. automotive crises of the 70s and 80s, when a focus cost reduction and efficiency forced radical changes in operating practices. Now, in the late 1990s, these same managers may not recognize the need nor share the vision for building a demand driven production system. Instead they may wish to continue to focus on those things that have made them successful in the first place. Without a doubt, the successful execution of a demand driven system strongly depends on top leadership - from the CEO to the Plant Manager - believing and buying into a "shared vision".[59] In the assembly plant, the leadership team sets the direction for the organization; they must drive the organization toward the development of flexibility-biased capabilities. These individuals must thoroughly understand the elements of the demand driven system and have committed to

---

[59] Kouzes and Posner, The Leadership Challenge, Jossey-Bass Inc. Publishers.

taking a long-term view to make the system successful. The leadership team does this by constantly reinforcing the development of flexible capabilities and by enabling others to act in ways that are consistent with this vision. Reinforcing also occurs through constant communication, coaching, and modeling demand driven principles. If developing flexibility is important to the plant manager, then the concept will be reinforced in meetings, decisions, incentives, recognition, and actions taken with the organization.

Measurement Systems

As performance measures become the basis of reward for an organization, they drive behavior.[60] In fact, what an organization *measures* reveals what an organization *values* - that is, what it believes is important. It is paramount to the success of this new production system, therefore, that the assembly plant's performance measures expand to include demand driven parameters. These measures alter the current behavior of plant management by aligning their objectives with the goals of the demand driven system. Traditional assembly plants focus on efficiency and quality based performance measurements, such as: vehicles per day (meet the production schedule), hours per vehicle, manufacturing cost per vehicle, # vehicles in repair float, etc. By contrast, demand driven measurements must not only comprehend cost and quality factors but also flexibility and service measures. But how should these measures be chosen? Research on designing performance measures indicates that there are a number of criteria for developing good performance measures.[61] First, for the measurements to be meaningful to the assembly plant, individuals must have the ability to directly impact the outcome of the measurements. Second, the measurements should be relatively few in number so as to focus performance and effort. Third, the measures should promote intra-functional communication so the total system performances of the business is optimized. Finally,

---

[60] Senge, The Fifth Discipline.

[61] Neely, A., Gregory, M., Platts, K., "Performance Measurement System Design," International Journal of Operations and Production Management, Vol. 15, No.4, 1995.

the measures should allow plants to compare their performance with other assembly plants.

By comparison, lean manufacturing indicators of flexibility include measures of manufacturing cycle time, lot size, and work-in process inventory.[62] Some lean manufacturing firms select performance measures as *determinants* of flexibility. These measures include setup times, product lead times, and the # of skills mastered per employee.[63] While some of these lean manufacturing measures could be applied to demand driven assembly plants, the environment suggests a slightly different measure of flexibility. For demand driven systems, the flexibility and service measurements should address questions like:

- Is the assembly plant able to build the "right vehicles at the right time"? (how many and which orders have to wait to be built?)
- What percentage of production date commitments are met?
- What is the order-to-delivery lead-time?
- How many assembly plant build constraints/rules exist?
- What is the measure of materials requirements volatility that results from demand variation?
- How flexible are workers - # jobs mastered per team?
- How many vehicles in repair float are over 1 day old?

Other factors to measure for direct assembly plant impact, although outside the control of the assembly plant include:

- How complex is the product line - how many part numbers must be managed?
- How many product variants are built?
- What is the total vehicle cost?
- How much finished goods inventory ($) is held (where applicable)?

---

[62] Womack, The Machine That Changed the World.

[63] Hall, R.W., Johnson, H.T., Turney, P., Measuring Up: Charting Pathways to Manufacturing Excellence, Business One Irwin, Homewood, IL, 1991.

These questions uncover the factors that directly and indirectly influence the ability of the assembly plant to respond to the market. They attempt to flush out management problems from systemic limitations. Both problems need to be addressed, but the action taken to address each problem varies significantly from one to the other. Just as important as the assembly plant measures, are those measures whose functional responsibility exists elsewhere in the organization and yet the impact of the decisions strongly impact the assembly plant. Strong process linkages must be created to strengthen and build process as well and functional ownership.

While this section deals with measurements at an assembly plant level, it is important to note that demand driven performance measures must span beyond the assembly plant to the upper ranks within the company to be truly effective. Divisional manufacturing managers as well as the President of Operations must be measured in their ability to obtain those demand driven goals in flexibility, service, quality, and cost. The performance measures at the upper ranks will be different from those on the plant floor; each level must have measures appropriate to the level of control. However, all will be aligned toward the same goals, the same focus, the same outcome. With a consistent message sent from the top down, performance measures provide the focus, accountability, and motivation to move a company forward - and closer to a demand driven environment.

Education

Education plays a key role in the implementation of demand driven systems. Education serves as the mechanism for translating the strategy into a language familiar and meaningful to the assembly plant. Education facilitates communication of a consistent message, helping to build a shared vision of the system. Furthermore, education provides an avenue for feedback, allowing specific assembly plant concerns to be aired and then addressed. Education allows the assembly plant to fully comprehend the nuances of the system so that once operational, individuals are able to make decisions that are consistent with the strategy and vision. Education provides knowledge, understanding, and training to improve planning and decision making. Education can spread best practices across a company and reinforce the use of common processes. Education content and depth will vary across the plant depending on the impact and level of knowledge required. "This is where we are headed" information should be communicated to every worker and manager in the assembly plant. To a set of targeted individuals, education may include specific discussion of roles, responsibilities, processes, and mechanisms required to operate in the new environment. While education is critical especially at the beginning stage of implementation, assembly plant personnel will require ongoing education and training as well. In working through a change effort, the real challenges are likely to surface after the initial implementation stages. Interaction among implementation personnel in other demand driven plants can diffuse information and aid in the education effort.

Developing Skill-sets

Demand driven systems require the development of new organizational capabilities. Demand driven systems strongly depend on cross-functional process linkages as compared to the functional hierarchical linkages present in traditional systems. These linkages require individuals at lower levels of the organization to communicate more frequently across functional boundaries. The interaction and process dependency across groups commands individuals to possess a wider scope of process knowledge than previously required. This requires the development of new organizational capabilities in the wake of implementation. It also reinforces that skill development, training, and organizational changes must be expected and planned with this level of change. Time for organizational learning must be budgeting throughout the implementation phase. Early learning through simulation and prototyping new processes can help uncover plant specific concerns that may be expensive / difficult to fix once the system is fully implemented. Interaction with and travel to other plants or individuals already using the system can also help transfer knowledge and information more rapidly than can a written process guide. Due to limited knowledge of the new system and how it will impact existing processes, it is impossible to predict exactly what problems will arise during system implementation. Therefore, it is important for individuals to practice the new skills in a simulated environment *prior* to actual implementation.

As skill sets develop and system linkages increase, it is also important to identify the process owners who will actively facilitate the change processes. As such, an explicit plan to communicate key information (Who is responsible to make policy changes?, How conflicts are settled?, What are the functional organizational responsibilities?) must be developed and distributed well in advance of implementation.

Managing the transition

How the assembly plant manages the transition from a traditional to a demand driven system is important to the implementation strategy. For example, what type of transition model is selected: a smooth curve, large step function or series of step functions or curves? The transitional model choice will be influenced by a number of factors. One influence factor is the amount of organizational learning or change required for system implementation. The more change and learning required, the slower the organization will wish to transition. The transitional model choice may also depend upon how much risk the implementers are willing to accept during the transition. A step function approach assumes an "instantaneous response" moving from one system to the other. The potential for production interruption, however, makes this approach high risk. Alternatively, a smooth curve transition assumes a ramp up in one system while the other system is ramping down. Yet his requires extra effort and redundancy, since both systems must operate simultaneously.

Perhaps more important to implementation than the transition model chosen is the way the transition is managed to steady state. As discussed earlier in the Leadership Section, enlisting the full support and involvement of the plant manager and his/her staff is an important first step in the implementation process. Strong support and commitment from the leadership team will rally support within the organizational ranks and facilitate the formation of a strong plant implementation team. *Who* is selected to participate on the implementation team is very important; it will signal to the remainder of the organization how serious to take the implementation effort. If fairly low level staff with little organizational power are asked to represent functional areas, less respect and attention will be paid to the implementation effort. Likewise, the amount of attention and status paid to the implementation issues are also important. Does the plant's leadership team attend periodic status reviews? Are the implementation issues discussed frequently? Again, these factors are important because they signal implicitly the depth of the assembly plant's commitment to implementing the new production system. By examining the organizational response to the implementation effort, it will be easy to distinguish those plants who believe the system to be a "fad" from those plants take the system earnestly.

It should be noted that the plant's (and plant manager's) response to the transition will also depend heavily on how the implementation is politically managed elsewhere in the company. If the system elicits attention and discussion in top management circles, then feedback will cascade from multiple directions to the assembly plant. Pressure exerted from the upper ranks of the organization - in translating expectations and prompting feedback - will influence the plant's response. Furthermore, the amount of support provided from outside ("SWAT Team") organizations to aid the implementation effort will influence the plant's readiness to accept the implementation challenge. Outside support can speed implementation and prompt a more thorough and organized implementation effort.

In addition to the political factors, how the plant chooses speed of the ramp up is another critical factor to successful transition. One way to improve ramp-up speed is to identify and institutionalize system *enablers* that can be implemented prior to full system implementation. These enablers would be systemic changes that can be pulled ahead into existing production systems to smooth implementation. Another way improve ramp-up speed is to insist on the use of common processes and systems. Ideally these processes would be identified as best practices critical to smooth and satisfactory system operation. However, these common processes must be balanced by an understanding for the need of individual ownership and commitment on part of the assembly plant personnel. Overuse of common process can unfavorably impact the plant's acceptance of the system and willingness to change; i.e., do they feel it is being "pushed down their throats" or is there an element of self determination in the process? Where processes are not identified as process sensitive or specific, the system should allow for exceptions or tailoring to suit individual needs. Also an avenue for plant-specific feedback for process change and improvement is important for continuous improvement nature of the system.

A final consideration in managing the transition to a demand driven system is the willingness of the assembly plant to accept short term set backs as the plant begins to establish flexibility-biased capabilities for the long term. For example, during this transition, the plant may need to increase buffers - people, parts, capacity - in order to build flexibility and improve response. Implicit here is the tradeoff and associated costs with holding buffers of raw materials, people, and capacity versus holding buffers of finished goods inventory. The acceptance of these losses must be balanced with a need for strong discipline in working to improve flexibility without short term increases in costs. Eliciting the help of workers at every level of the organization in moving toward demand driven goals is required to improve capabilities for the long term.

In summary, suggestions for successfully managing the transition to a demand driven system include:

- *Choose appropriate implementation model*
- *Enlist strong support of leadership team*
- *Form plant implementation team*
    - *Identify high status functional owners up front*
- *Identify and institutionalize key enablers prior to implementation*
- *Implement new process measurements*

- *Use common processes where appropriate*
    - *Allow differentiation in less-critical processes*

- *Be willing to accept short term pain for long term gain*
    - *Increase discipline and involvement*

Section 4
Demand Driven Production Scheduling Simulation

In the preceding sections, some of the strategic and tactical issues involved with the implementation of a demand driven production system were explored. Section 4 further explores this environment utilizing a computer tool to simulate a production scheduling system. The section specifically explores production control's ability to schedule orders while contending with factors that limit order flow. The section begins with a brief overview of the simulation and its operation, followed by subsections describing the simulation parameters, measurements, results, and conclusions.

4.1 Simulation Description

The simulation models a demand driven scheduling environment. The simulation was designed primarily for illustrative purposes. It provides the reader a different context with which to understand the dynamic relationships involved in managing a demand driven system and it clarifies many of the issues that inhibit order responsiveness. To this end, the simulation explores how the assembly plant operating plan, build constraints, and related operating policies impact order flow into the production schedule. Figure 4.1 provides a model of the production scheduling simulation.

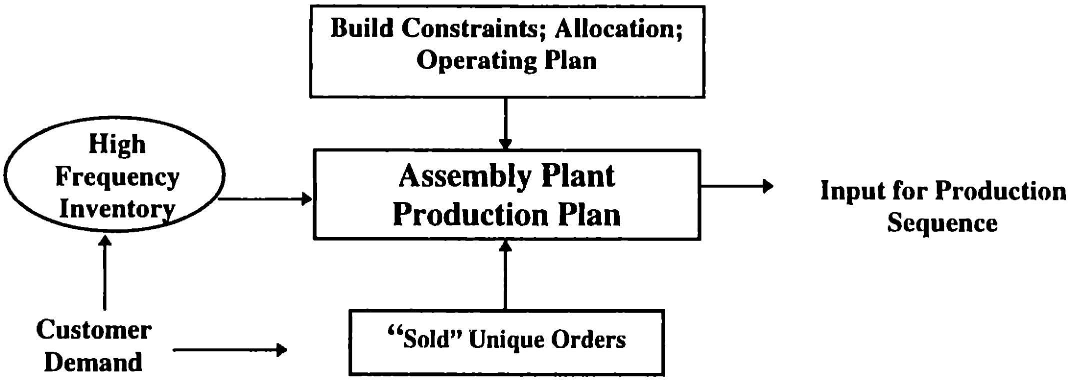


Figure 4.1: Production Scheduling Model

Two kinds of order streams exist in the simulation: high frequency orders and unique orders. High frequency orders are those vehicles identified through historical analysis to be frequently ordered (in high customer demand). For simulation purposes, high frequency orders are held exclusively in finished goods inventory. All vehicles not deemed high frequency are considered potential unique orders. Based on demand requirements, the simulation randomly generates a unique order using a special unique order algorithm. Regardless of order type, customer demand follows a Poisson process and is simulated using the negative exponential distribution.[64]

The simulation operates with two primary goals. First, schedule every unique order on the day it is ordered. If the order cannot be scheduled immediately, the simulation maintains the order in queue (up to seven days) until it can be scheduled. Second, schedule high frequency orders in order of "most deserving" priority. To accomplish this, the simulation keeps track of actual inventory levels and maintains a measure of current customer demand. High frequency orders with higher build priority are scheduled first.

---

[64] Watson, H.J., "Probability Distributions and Their Process Generators," Chapter 5, Probability Distributions and Their Process Generators, John Wiley & Sons; USA, 1981.

The simulation considers three factors that may inhibit order flow into the schedule: build constraints, the assembly plant operating plan, and the demand allocation. *Build constraints* can restrict order flow in two ways. First, an upper limit as a percentage of the total build is defined for each vehicle model. This limit determines how much of each model can be built in the assembly plant each day. Second, an upper limit as a percentage of total build is defined for specific vehicle options. This limit defines how much of each option can be built in the assembly plant each day. For example, the option for uplevel molding is limited to 32%. This means that only 384 vehicles specified with uplevel molding can be built on a given production day.

Like build constraints, the *assembly plant operating plan* also influences order flow. The operating plan consists of plant capacity per day (vehicles/day) and the vehicle model allocation for the assembly plant. The operating plan inhibits order flow anytime demand exceeds capacity for a given day. That is, if the combined number of unique and high frequency vehicle demand exceeds the number of vehicles that can be built in a day, then all orders cannot be scheduled. These orders must wait until the next day (or days, depending on the limitations and size of the order queue) to be scheduled.

Finally, the *demand allocation* impacts order flow. In the context of this simulation, the demand allocation is defined as the percentage breakdown of demand between high frequency and unique orders. For instance, a 70%-30% high frequency-unique order split may be interpreted to mean, "of the total number of vehicles demanded, 70% of customers desire high frequency vehicles, while 30% of customers demand unique vehicles." The allocation inhibits order flow when vehicles demanded by customers interact with the assembly plant constraints and/or operating plant, thereby delaying orders from the schedule.

4.2 Model Overview

The simulation schedules orders daily, as outlined in the flow diagram (Figure 4.2).

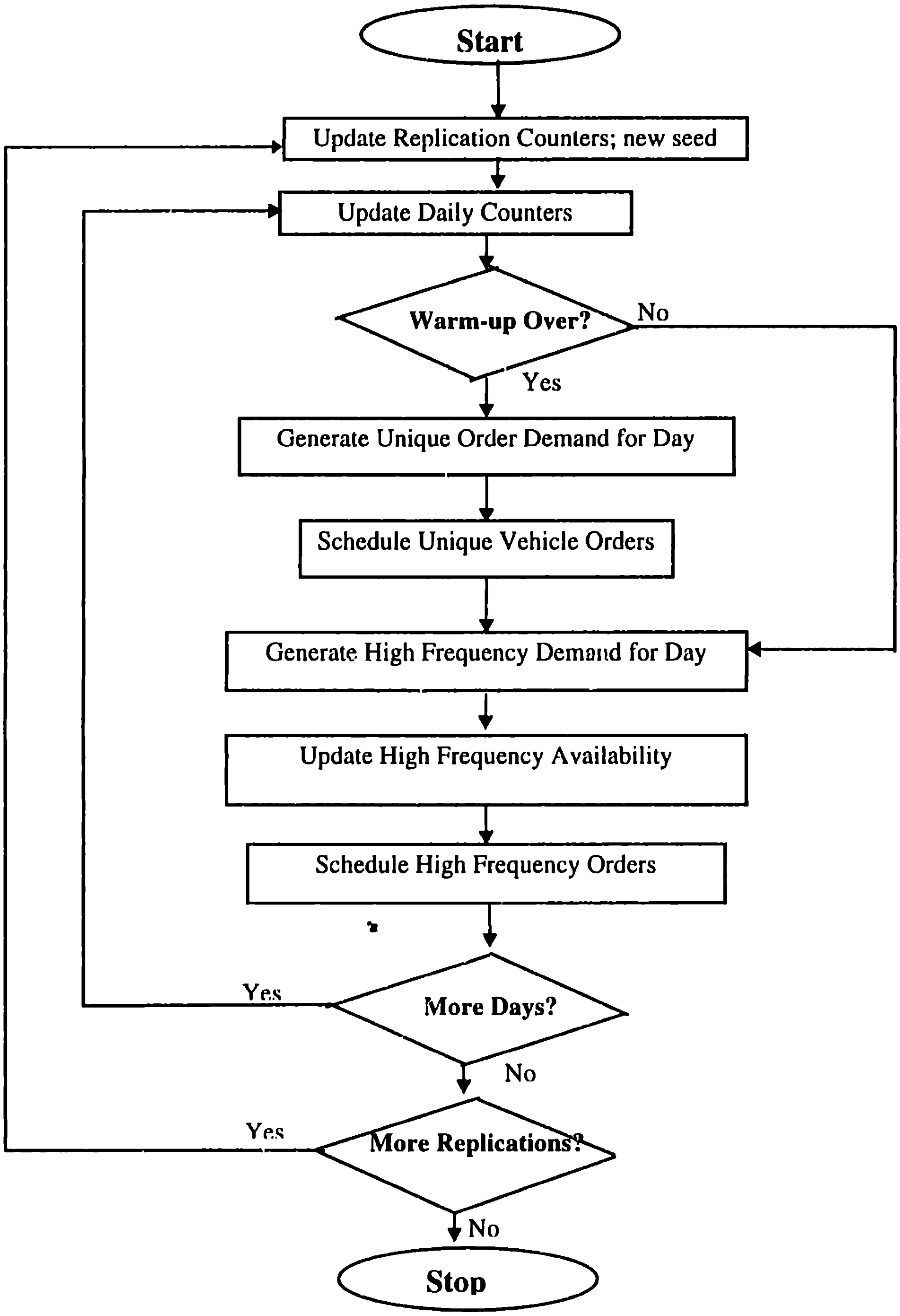


Figure 4.2 Production Scheduling Flow Diagram

The simulation begins each day by updating counters. Next, it checks to see whether the warm-up cycle is completed. The warm-up period allows a pre-determined level of inventory to build up prior to fulfilling any customer orders. In order to build this inventory quickly, only high frequency vehicles are produced for the first 12 days of each simulation run. No vehicles may be pulled from inventory during this period. After 12 days, unique orders are allowed and vehicles may be pulled from inventory. Statistics collection begins when the warm-up cycle is completed.

The simulation next generates the unique and high frequency order daily demand (Poisson). The simulation then selects unique vehicle orders for the day's build using a special algorithm. This algorithm randomly selects the model, option content, color, and trim level for each unique order from a pool and places the completed orders in queue behind any orders left from yesterday. These queued unique orders are then scheduled for production. Scheduling involves determining whether the model, option content, color and trim level violate any of the assembly plant constraints or operating plan criteria. If they do not violate any of the rules, they are successfully scheduled for production. If an order violates a rule, then it is bumped (successively) to the next days' order queue.

Once all feasible unique orders have been scheduled, the high frequency orders are prioritized for build. The simulation determines high frequency order build priority based on current inventory levels and customer demand. This priority queue is then scheduled for production in much the same way as the unique orders are scheduled. The exception to this, however, is that high frequency orders do not get bumped to the next day. Instead, if a high frequency order cannot be scheduled, this will be reflected in the priorities for the next days' build. As the inventory level of a high frequency vehicle decreases, its priority in the build queue increases. Once the limit of high frequency orders is scheduled, the simulation updates the replication counters and then compares the number of simulation days completed to the number specified. If more days are specified, the simulation starts over again. If the number of days completed has reached the number of days specified, that replication of the simulation ends and the statistics are summarized.

If another replication of the simulation is specified, the simulation runs with the same initial conditions but the Poisson processes select different starting seeds so that a demand varies for each replication. Once all replications have been completed, the statistics are assembled by averaging the individual runs.

4.3 Simulation Parameters

This scheduling simulation is data driven. This section describes the parameters driving the simulation and the default settings used in Section 4.5.

Global Parameters and Settings

- *High Frequency Vehicles:* 192 unique combinations of sales options (model, option content, trim, and color) identified as in demand based on a sales analysis. For this simulation, high frequency vehicles are "held" as finished goods inventory.
- *Unique Orders:* All configurations not deemed high frequency are considered potential unique orders. Based on demand requirements, the simulation randomly generates a unique order using a unique order algorithm.
- *Plant Capacity:* 1200 vehicles/day
- *Number of simulation days:* Each simulation runs for 240 production days
- *Number of warm-up days:* The warm-up period allows sufficient levels of inventory to build up prior to fulfilling any unique orders. To build a sufficient level of finished goods inventory, only high frequency vehicles are produced for the first 12 days of each simulation run. After 12 days, unique vehicle orders are allowed and vehicles may be "pulled" from inventory.
- *Number of replications:* The number of executions of the simulation where each replication starts with the same initial conditions, but the Poisson processes have different starting seeds. Simulation was completed based on 6 replications for each run.
- *Minimum inventory level:* 10 days demand
- *Maximum inventory level:* 30 days demand

Key Variables

- *Customer Demand:* Simulate based on three different demand levels - 1000 vehicles/day, 1200 vehicles/day, 1400 vehicles/day

- *Demand Allocation:* Defined as the percentage of demand allocated for building high frequency versus unique orders. Five operational settings are explored ranging from 50% to 90% high frequency orders.

Assembly Plant Constraints

Thirteen Assembly Plant Constraints are used in the simulation (the last 4 are marketing model allocations):

1. Two-Tone Paint
2. Uplevel Molding
3. Red Paint
4. Trailer Hitches
5. Manual Shift Transfer Case
6. Shields
7. All wheel Drive
8. STRP
9. Checker 2WD
10. Checker 4WD
11. Robot 2WD
12. Robot 4WD

4.4 Measurements/Output

The production scheduling simulation collects the following output statistics:

For Each High Frequency Configuration:

- Average Inventory
- Minimum Inventory
- Maximum Inventory
- Days Below Inventory Minimum
- Days at Inventory Maximum

For Each Assembly Plant Constraint:

- Average Usage (% of build)
- Number of High Frequency Orders Below Min Caused
- Number of Unique Orders Delayed by at Least One Day

For Unique Vehicle Orders:

- Total Unserviced Unique Orders

- Total Bypassed Customers (No build)
- Unique Order Wait Time Histogram (0 to >7 days)

4.5 Simulation Results

The simulation results are divided into two parts. The first part explores the utilization of constraints under three different demand scenarios: capacity exceeds demand, capacity equals demand, and capacity less than demand. For each scenario, the number of orders delayed from schedule are tracked and the constraints that limit order flow are identified. Constraints that delay orders are called *limiting constraints.* Of the thirteen original constraints, five constraints (1 option constraint and 4 model constraints) are limiting constraints in at least one scenario: red paint, Checker 2 wheel drive, Checker 4 wheel drive, Robot 2 wheel drive, and Robot 4 wheel drive. The graphs presented in this section present these five constraints in each scenario.

The second part of this section examines the effects of limiting constraints. The impact to unique vehicle orders is explored by tracking the percentage of unique orders scheduled within one day. Furthermore, to gain an understanding of the impact to high frequency orders, the number of high frequency configurations that fall below minimum inventory levels is tracked. Finally, some of the high frequency inventory side effects are presented in the final sections.

Part I: Demand Scenarios

Capacity Exceeds Demand

At a demand rate of 1000 vehicles per day, constraints did not delay scheduling in four of the five scenarios tested: 60%, 70%, 80%, and 90% high frequency vehicle demand. In these four cases, neither the operating plan nor the plant constraints prevented any orders from being scheduled. However, at 50% high frequency vehicle demand, 270 unique vehicle orders were delayed by at least one day and 2300 vehicle orders were forced below minimum inventory levels. Figure 4.3 illustrates the number of orders delayed in each scenario tested.

Figure 4.3: # of Orders Delayed by Limiting Constraints Capacity 1200 vehicles/day; Demand 1000 vehicles/day

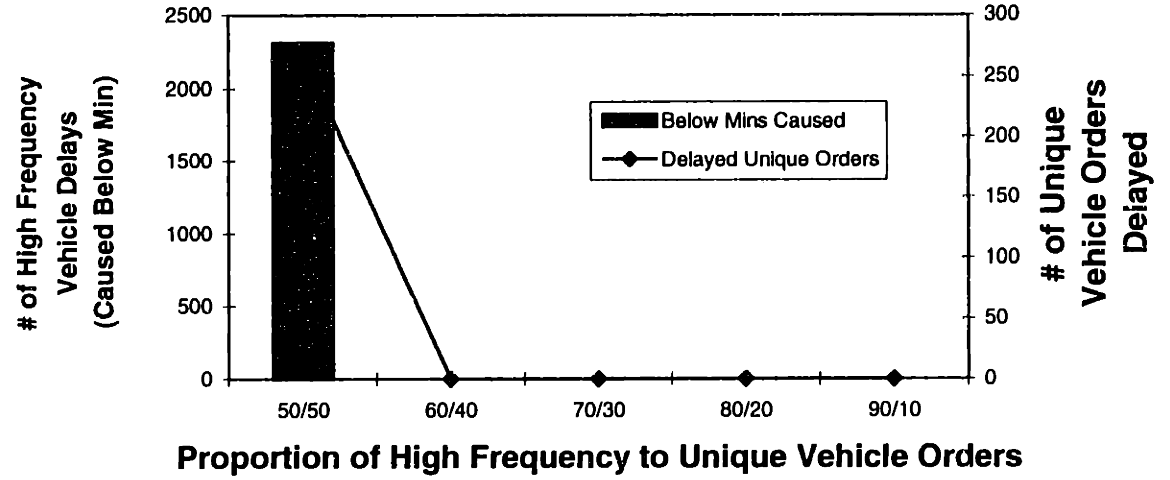
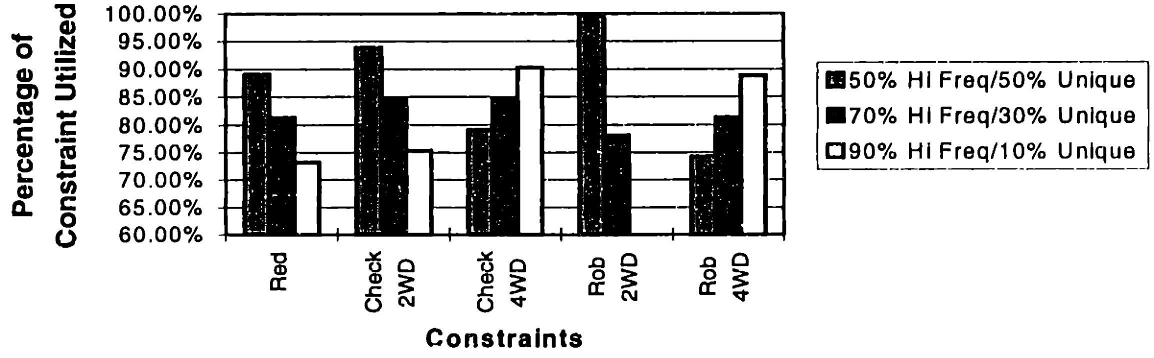


Figure 4.4 pictorially represents how much of each of the top five constraints is utilized in each scenario. This "utilization profile" tracks constraint usage at various high frequency to unique vehicle order demand points. As shown in Figure 4.4, at 50% high frequency vehicle demand, the Robot 2 wheel drive constraint reaches its build limit. Bumping against this constraint limit, in turn, forces the delay of high frequency and unique vehicle orders presented in Figure 4.3.

Figure 4.4: Constraint Utilization Profile Analysis of Limiting Constraints

Capacity 1200 vehicles/day; Demand 1000 vehicles/day

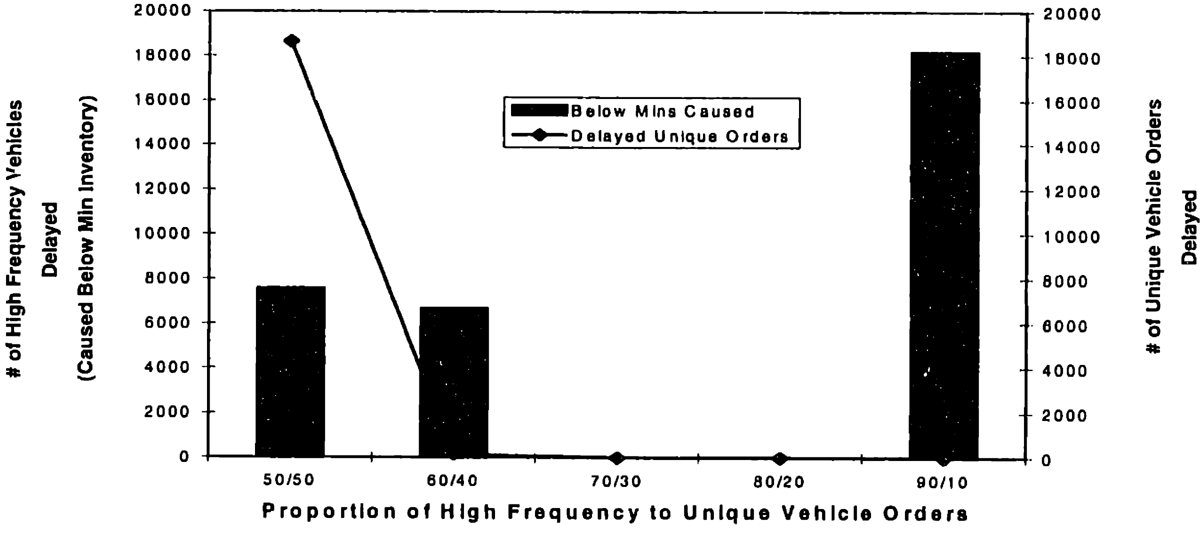


Interestingly, as the high frequency vehicle demand increases from 50% to 90%, the constraint utilization profile also changes. As high frequency vehicle demand increases, the utilization of red paint, Checker 2 wheel drive and Robot 2 wheel constraints actually decrease. At the same time, the utilization of Checker 4 wheel drive and Robot 4 wheel drive constraints increase. This reflects a shift in model and option demand with the changing order pools.

Demand and Capacity Equal

At a demand rate of 1200 vehicles per day, the model shows constraints inhibiting order flow at three high frequency vehicle demand points: 50%, 60% and 90% of demand. As shown in Figure 4.5, over 18,000 unique vehicle orders and 7500 high frequency vehicles are delayed by constraints when high frequency vehicle orders are 50% of demand. Similarly, at 60% high frequency vehicle demand, approximately 7000 high frequency vehicles are delayed by constraints, while no unique vehicle orders are delayed. No orders are delayed in either 70% or 80% high frequency demand scenarios. However, when high frequency vehicle demand reaches 90%, over 18,000 high frequency vehicles are delayed, while no unique vehicle orders are delayed.

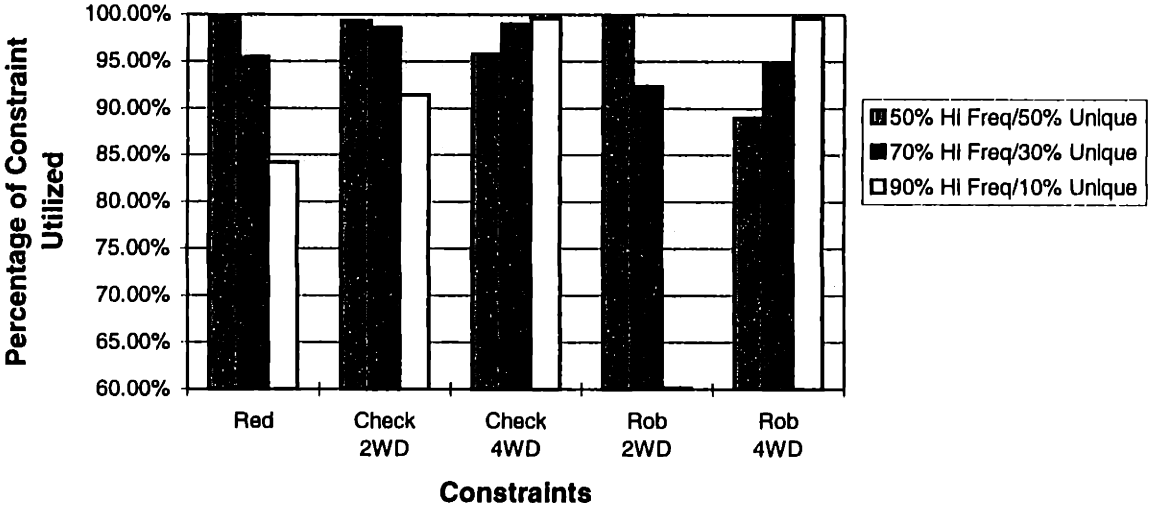
Figure 4.5: # of Orders Delayed by Limiting Constraints
Capacity 1200 vehicles/day; Demand 1200 vehicles/day



The constraint utilization profile at the 1200 vehicle/day demand rate is presented in Figure 4.6. The constraints inhibiting flow at 50% high frequency vehicle demand are Checker 2 wheel drive and Robot 2 wheel drive. While red color is utilized at 99% of its limit, it did not constrain any orders from the schedule. Interestingly, all of the unique vehicle orders in this scenario were delayed by the Robot 2 wheel drive constraint, while the high frequency orders were almost twice as likely to be delayed by the Checker 2 wheel drive constraint than the Robot 2 wheel drive constraint (4800 versus 2800).

As high frequency vehicle demand increases, utilization of three constraints (red paint, Checker 2 wheel driven and Robot 2 wheel drive) decreases. In response, the utilization of the 4 wheel drive constraints increase. At 90% high frequency vehicle demand, Checker 4 wheel drive and Robot 4 wheel drive constraints limit over 18,000 high frequency orders from immediate scheduling.

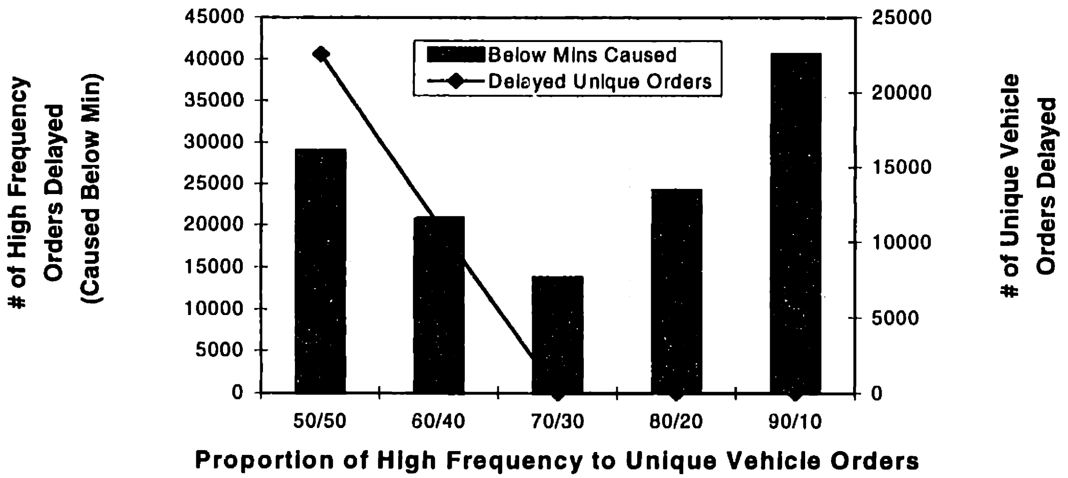
Figure 4.6: Constraint Utilization Profile
Analysis of Limiting Constraints
Capacity 1200 vehicles/day; Demand 1200 vehicles/day



Demand Exceeds Capacity

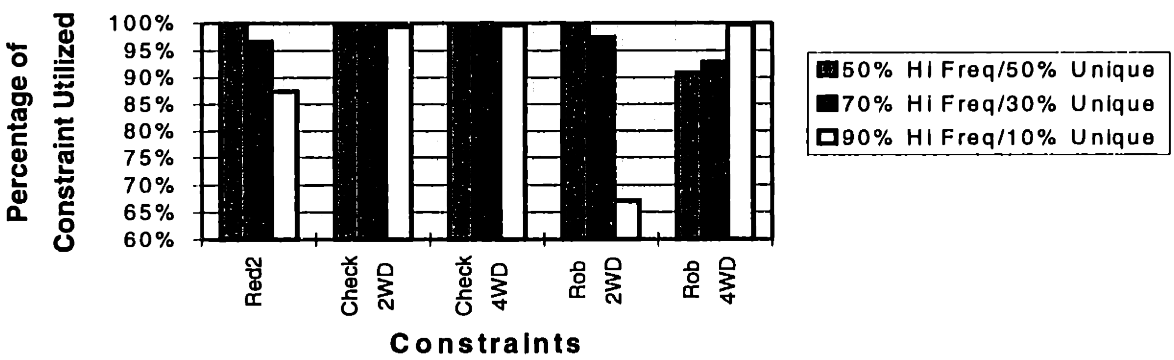
When the demand rate increases to 1400 vehicles per day, the number of orders delayed increases dramatically. Regardless of demand allocation, high frequency orders are delayed and below minimum inventory levels result. Likewise, unique vehicle orders are delayed when high frequency vehicles make up 50% and 60% of demand. Above 60% high frequency demand, unique vehicle orders are not delayed; however, since they are scheduled before high frequency orders, they effectively consume the available constraint capacity. Figure 4.7 illustrates the findings.

Figure 4.7: # of Orders Delayed by Limiting Constraints
Capacity 1200 vehicles/day; Demand 1400 vehicles/day



The constraint utilization profile at the 1400 vehicle/day demand rate is presented in Figure 4.8. At the 50% high frequency vehicle demand, all constraints with the exception of Robot 4 wheel drive are fully utilized. As high frequency vehicle demand increases to 90%, Checker 2 and 4 wheel drive constraints remain fully utilized and the Robot 4 wheel drive constraint increases until it also becomes fully utilized. Red color and Robot 2 wheel drive constraints no long limit order flow.

Figure 4.8: Constraint Utilization Profile
Analysis of Limiting Constraints
Capacity 1200 vehicles/day; Demand 1400 vehicles/day



Part II: Constraint Effects

Unique Vehicle Order Wait Time

Since unique vehicle orders are given priority in the scheduling algorithm, they are processed each day before high frequency vehicles are selected and scheduled. This decision policy enables unique vehicle orders to be processed quickly, almost regardless of demand. In every scenario tested, the simulation schedules over 90% of unique vehicle orders within one day. Table 4.1 outlines these statistics.

Table 4.1: Percentage of Unique Vehicle Orders Scheduled Within One Day

High Frequency to Unique Vehicle Ratio		Customer Demand	
	1000/day	1200/day	1400/day
50-50	99%	95%	96%
60-40	100%	99%	92%
70-30	100%	100%	100%
80-20	100%	100%	100%
90-10	100%	100%	100%

High Frequency Vehicle Inventory

Although most all unique vehicle orders are scheduled quickly, high frequency vehicle availability varies considerably depending upon the scenario. As Table 4.2 indicates, the largest influence over high frequency vehicle availability is total demand. When demand continually exceeds plant capacity, high frequency vehicles eventually fall below minimum inventory levels, regardless of the demand penetration. As one would expect, availability improves dramatically when capacity meets or exceeds demand. In these scenarios, however, other factors begin to influence vehicle availability. Although aggregate demand can be met by available capacity, availability becomes strongly influenced, and often limited, by operational variables, such as plant constraints, high frequency vehicle demand penetration, and the decision policies.

For instance, in the scenario with 1200 vehicles/day demand (90% high frequency vehicles), over 155 different configurations fall below minimum inventory levels. How can this happen when capacity meets demand and unique vehicle orders will only tap a small amount of the available constraints? This is a situation where high demand (90% of capacity) for a limited configuration delays the scheduling activity. In fact, these configurations fall below minimum levels because demand for two model codes Checker 4 wheel drive and Robot 4 wheel drive exceeds available constraint capacity. The configurations delayed all demanded either Checker or Robot 4 wheel drive, in quantities that exceed available assembly plant constraints limits.

At 70% and 80% high frequency vehicle penetration (1200 / 1000 vehicles/day), no configurations fall below minimum levels. With unique vehicle orders composing 20 / 30% of total demand, a larger variety and mix of model/option content is selected for build. Unique vehicle orders contain higher demand for red vehicles and 2 wheel drives, while high frequency vehicles contain higher demand for 4 wheel drives. In these scenarios, unique and high frequency order requirements balance, allowing both order type requirements to be satisfied concurrently. In fact, it is not until unique vehicle order demand grows to 40-50% that build constraints again begin to force high frequency inventory to below minimum levels. In these cases, unique vehicle orders bump up against the constraints for Checker and Robot 2 wheel drive. This has two affects. First, it delays a relatively small number of 2 wheel drive unique vehicle orders by at least one day. Second and perhaps more importantly, unique vehicle orders begin to "use up" these constraints before high frequency vehicles have a chance to serviced. As a result, unique vehicle orders continue to be fairly quickly scheduled while high frequency configurations with constrained models / options are delayed from build.

Table 4.2: Number of High Frequency Configurations Below Minimum (Out of 192 total)

High Frequency to		Customer Demand	
Unique Vehicle Ratio	1000/day	1200/day	1400/day
50-50	12 (8%)	36 (19%)	192 (100%)
60-40	0	36 (19%)	192 (100%)
70-30	0	0	192 (100%)
80-20	0	0	192 (100%)
90-10	0	155 (81%)	192 (100%)

Constraint Side Effects

In the ideal production setting, high frequency inventory levels fall between the min and max inventory targets. These min and max limits act as control limits for inventory. While short term constraints, demand fluctuations, or delays may influence the actual inventory level, rarely should inventory be maintained for a long period of time outside the targets. In less ideal circumstances, high frequency vehicle inventory becomes more variable. For instance, the simulation demonstrates cases where limiting constraints begin to significantly inhibit order flow and high frequency stocks are impacted. Inventory of those configurations containing constrained model/options slowly falls below minimum stocking levels and approaches a constant. Interestingly as this occurs, the inventory level of configurations with options/models unaffected by the constraints begins to grow. Eventually these configurations hit maximum inventory levels and tend to maintain this maximum level over time. Figures 4.9 and 4.10 illustrate this phenomena. The figures are reflective on one scenario run over a variety of days: Capacity and demand are both equal to 1200 vehicles/day; operating policy of 50% high frequency and 50% unique vehicle orders is utilized.

Figure 4.9: Constrained High Frequency Configuration Inventory Level Over Time

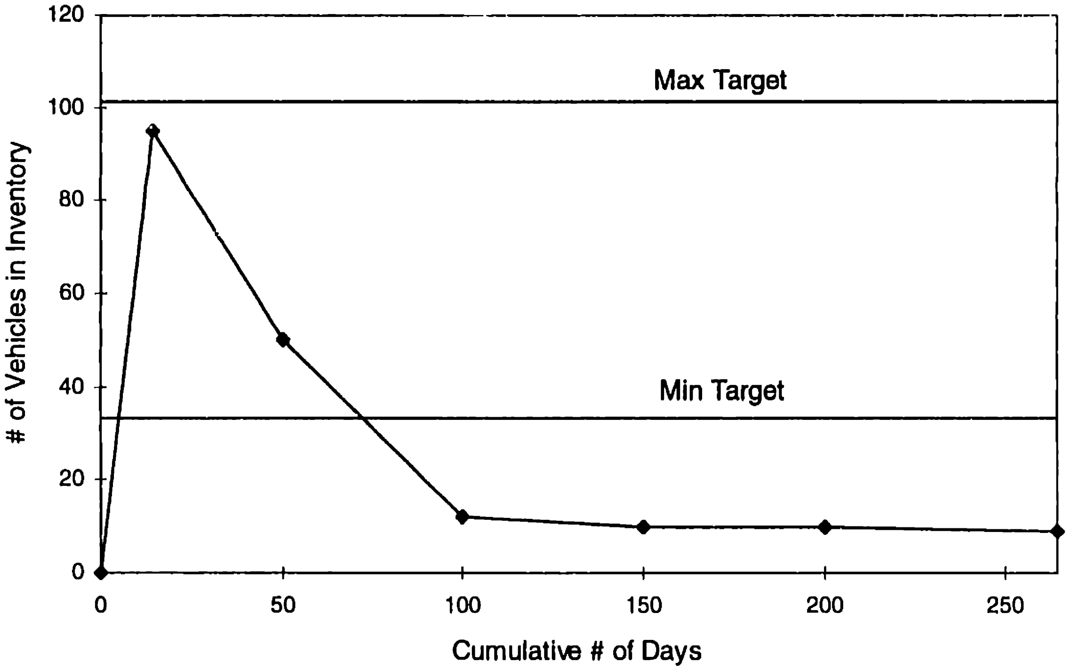


Figure 4.10: Uncontrained High Frequency Config Inventory Level Over Time

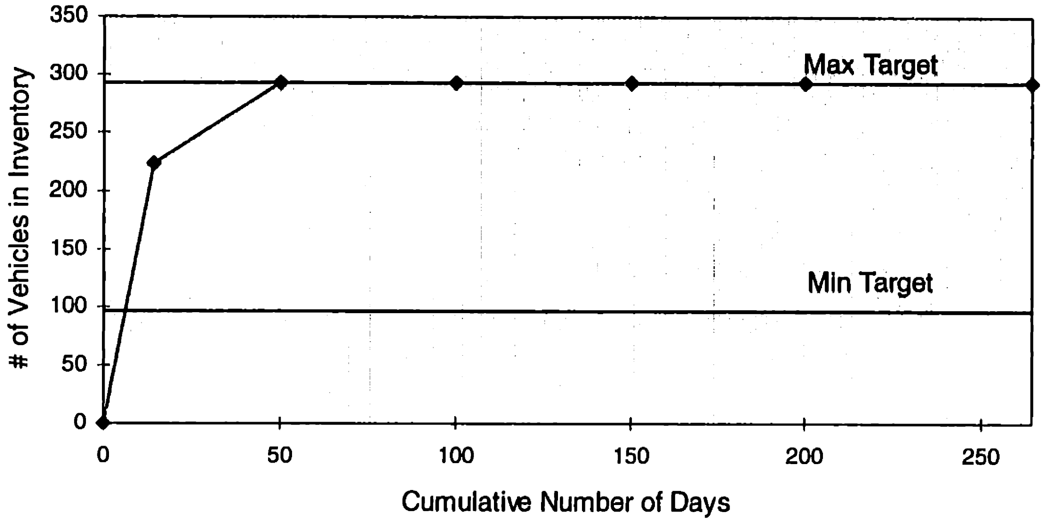


Figure 4.10 shows a high frequency configuration affected by a limiting constraint. Inventory builds through the warm-up period, after which inventory levels fall until they eventually level off to approximately 10 vehicles. Conversely, Figure 4.11 tracks a high frequency configuration unaffected by a limiting constraint. Inventory quickly builds until it levels off at the maximum inventory target near the 50th day. While Figures 4.10 and 4.11 demonstrate rather extreme examples of what happens when constraints limit order flow over time, the simulation shows similar trends in inventory levels anytime constraints limit order flow.

4.6 Simulation Conclusions

The scheduling simulation illustrates some of the challenges involved in scheduling vehicles in a demand driven environment. It serves as an alternative lens with which to view and understand key relationships and systemic limitations involved with this activity. While the simulation simplifies an actual production scheduling environment, it is directionally accurate in highlighting trends and identifying potential management issues. Results of the simulation reinforce the following concepts:

1. *The production system can successfully schedule both unique and high frequency orders.* The plant can successfully manage a predetermined level of unique vehicle orders, however, there is clearly a trade-off between capacity and customization. As the penetration of unique vehicle orders increase beyond this point, order flow and response time diminish. Conversely, at extremely low levels of customization, capacity is constrained due to excessive demand for selected options / models containing constraints.

2. *Assembly plant constraints, operating plan, and demand allocation all influence order flow and order response time.* Order flow largely depends on the relative demand allocation between high frequency and unique orders, the content of the high frequency vehicles, and the interaction of the order content with the assembly plant constraints.

3. *The factors inhibiting order flow are dynamic.* The scenarios modeled in the simulation demonstrated a sensitivity to five limiting constraints. As the order pool changes, the impact of the constraints change. Limiting constraints in one scenario are not limiting in others.

4. *The factors inhibiting order flow influence high frequency vehicle inventory levels and vehicle availability.* When the simulation was unable to build a high frequency configuration equipped with a limiting constraint, it selected and built a different configuration (one that was not equipped with the constraint). Over time, this succeeded in building relatively high inventory levels of "non-constrained" configurations and low inventory levels of constrained configurations.

5. *The scheduling algorithm itself influences order flow.* The algorithm inherently contains decision rules for preference certain orders over others. In the simulation, unique vehicle orders were scheduled before high frequency vehicles, regardless of high frequency vehicle demand. This provided high unique vehicle order service rates while at times sacrificing high frequency configuration availability.

Section 5
Conclusions

Although automotive sales and distribution methods have changed little over the past decade, significant changes are underway in the automotive marketplace. Industry trends worldwide reveal the emergence of a new *demand driven* production format. This new format, preempted by the use of information and computer technology, is driven by the interests of customers, dealers, and manufacturers alike. It allows automakers to manage the value chain with improved communication and real-time access to information. It seeks to attack many of the existing system inefficiencies, costs, and customer dissatisfiers, namely vehicle availability, selection, and responsiveness. Encouraged that the new system can lower costs while also improving selection and delivery, nearly all automakers have begun to experiment with one form or another of this new demand driven format.

One of the primary challenges of implementing a demand driven system is to identify and eliminate those variables that create delay and stagnation. To this end, demand driven producers strive to eliminate production delays, assembly plant constraints, and excessive product / process complexity. Furthermore, they seek to develop new competencies that center on building and nurturing flexibility-biased capabilities; that is, developing skills that allow manufacturers to respond to changing customer demands. These skills not only allow the manufacturer to respond faster but also to act with a higher degree of accuracy, building "the right automobiles at the right time."

In addition to a functional transformation, there are five organizational factors critical to the implementation success of a demand driven system. First, a *leadership team* endowed with a total process focus is required to propel the concept forward. Second, the selection of *performance measurements* that align the individual and business unit objectives with the total organizational goals is key to the development of flexibility-biased capabilities. Third, *education* serves as the conduit for communicating information and transferring knowledge in new organization. fourth, nurturing the development of *new skillsets and organizational capabilities* is necessary to support the new challenges involved. Many of these challenges result from increased cross-functional interaction and faster decision making required at all organizational levels. Fifth and finally, *how the transition is supported and managed* via the implementation team is critical to its success. This includes careful consideration of implementation team selection, ramp-up speed, key enablers, and the use common processes.

To demonstrate some of the challenges of managing a demand driven system, a demand driven scheduling environment was simulated. The simulation highlights the importance of reducing assembly plant constraints and developing flexibility-biased capabilities. It further reinforces the idea of using simple, yet dynamic decision rules to determine build priorities and manage resources effectively. Most importantly, the simulation demonstrates that as customer needs change, the manufacturing system must have the ability to dynamically adjust to meet these needs.

It is apparent there are many benefits involved with a demand driven production system. The system should allow automakers to not only reduce lead-times and improve responsiveness, but it also forces them to actually listen and respond to customer demands. Focused on customer needs, communication and feedback increases. Customers win with improved products, availability, delivery and service. Manufacturers (and dealers) win with lower costs, more efficient operations, and increased sales. The concepts and ideas underlying demand driven systems may not be revolutionary, but the implementation challenges are large for many automotive manufacturers. The decision to move toward a demand driven production system reflects not only a shift in manufacturing focus, it signals a shift *in manufacturing strategy.* This strategic shift will require manufacturers to make dramatic changes to their functional, structural, and organizational systems. This fundamental shift is not only required for successful implementation, it the key to a successful demand driven system.

References

Automotive Facts and Figures, Automobile Manufacturers Association, Inc: Detroit, MI, Editions 1939-1994.

Birch, S., "The Art of Taking Time Out," Automotive Manufacturing, April 1996.

Brown, J., "The Economics of the Car Distribution System," International Car Distribution Programme Ltd, Research Paper No 1/96, November 1995.

Brown, J., "Customer Driven Delivery - International Implications," International Car Distribution Programme Ltd, Research Paper No1/94, January 1994.

"1996 Cars Reliability," Consumers Report, April 1996, pg. 50-51.

"Cadillac Offers Faster Delivery," The Patriot Ledger, April 5, 1997.

"Cadillac Sets New Standard With National Rollout of Custom Xpress Delivery," PR Newswire, Financial News Section, February 5, 1997.

Connelly, M., "Ford Takes Steps to Chop Delivery Time to 15 Days," Automotive News, February 17, 1997.

Connelly, M., "Ford Test Goal: 15 Days From Order to Delivery," Automotive News, July 29, 1996.

Cooke, J.A., "Agility Counts!" Traffic Management, August, 1995.

"Change at the Check Out," The Economist, March 4, 1995.

DeLeeuw, S., "Car Supply and Stocking Systems in Europe," International Car Distribution Programme, Research Paper No 10/95, July 1995.

"Fit To Be Tried and True," New York Times, April 6, 1997.

Ford Web Site, World Wide Web, URL http://www.fordvehicles.com/mustang/index.html, Vehicle Configurations, April 21, 1997.

Frame, P., and Child, C., "GM Dealers Will Lose Cash Bonus on Floorplan," Automotive News, December 9, 1996.

Hall, R.W., Johnson, H.T., Turney, P., Measuring Up: Charting Pathways to Manufacturing Excellence, Business One Irwin, Homewood, IL, 1991.

Harbour, M., Wade, P., Williams, G., Brown, J., Jones, D., "Managing New Vehicle Supply and Demand in the 1990's," Harbour Wade/RMI, Solihull, UK, 1992.

Hayes, R. and Pisano, G., "Manufacturing Strategy: At the Intersection of Two Paradigm Shifts," Production and Operations Management, Vol. 5, No. 1, Spring 1996, pg. 35-38.

Henry, J., "Volvo Want to Speed Delivery, Cut Inventory," Automotive News, September 4, 1995.

Huston, H., and Feast, H., "Lean Distribution To Cut VW Delivery Time," Automotive International, October 1996.

Jedlicka, D., "GM Tests Speedier Delivery," Chicago Sun Times, Financial Section, October 28, 1996.

Kouzes and Posner, The Leadership Challenge, Jossey-Bass Inc. Publishers, pg. 3-27.

Marsh, P., "Focus on the Job in Hand: Case Study," Financial Times, London Edition, October 2, 1996.

Mateja, J., "Cadillac Aims to Deliver the Right Car, Right Away," Chicago Tribune, Business Section, August 12, 1996.

McKesson, M., "Chrysler Plans 16-Day Delivery," Lansing State Journal, January 10, 1995.

McWilliams, G., "Whirlwind on the Web," Business Week, April 7, 1997.

Mercer, G., "Don't Just Optimize - Unbundle," McKinsey Quarterly, Third Quarter, 1994.

Nannery, M., "Levi's: Full Speed Ahead on Quick Response Drive," WWD, March 29, 1996.

Neely, A., Gregory, M., Platts, K., "Performance Measurement System Design," International Journal of Operations and Production Management, Vol. 15, No. 4, 1995.

"Nissan Central Stock Cuts Lead Times," Automotive International, April 1994.

"NS and Ford Sign Innovative Agreement," Railway Age, November 1996.

Phelan, M., "Stalking the Elusive 5-Day Car," Automotive Industries, November 1996.

Sawyers, A., "GMC Adds Regions to Delivery Test," Automotive News, March 17, 1997.

Sawyers, A., "VW Dealers Like 48-Hour Order Plan," Automotive News, April 7, 1997.

Sawyers, A., "VW: 48-Hour Delivery Looks Promising," Automotive News, February 10, 1997.

"Selling PCs Like Bananas," The Economist, October 5, 1996.

Senge, P.M., The Fifth Discipline, Currency/Doubleday, NY, 1990.

Stern, G., "GM Expands Plan to Speed Cars to Buyers," The Wall Street Journal, October 21, 1996.

Taylor, A., "How To Buy a Car on the Internet," Fortune, March 4, 1996.

"The Future of the Retail Auto Industry," Automotive Executive, July 1993, pg. 34.

"The Kindergarten That Will Change the World," The Economist, March 4, 1995.

"Two Tough Companies Learn to Dance Together," Harvard Business Review, Nov./Dec.1996.

Wade, P., "New Vehicle Supply Systems," J.D. Power Roundtable, Boston, October 1994.

Wards Automotive Yearbook, Fifty-Eighth Edition, Southfield, MI, 1996.

Watson, H.J., "Probability Distributions and Their Process Generators, Chapter 5, "Probability Distributions and Their Process Generators, John Wiley & Sons: USA, 1981.

Womack, J.P., Jones, D.T., Roos, D., The Machine That Changed The World, New York: Harper Perennial, 1991.