RAIL CAR EQUIPMENT AND LOGISTICS DESIGN STRATEGY FOR A LEAN AUTO MANUFACTURER

by

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Bachelor of Science in Mechanical Engineering, Brown University (1993)

Submitted to the Department of Mechanical Engineering and to the Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING
and
MASTER OF SCIENCE IN MANAGEMENT
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 1997

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ABSTRACT

Like many manufacturers today, Ford Motor Company is under increasing pressure to produce higher quality products with lower cost, and better delivery. Several strategies have been developed to meet these new challenges. The demands of these strategies have made it increasingly unattractive to ship parts from components plants to assembly plants by rail. Although rail used to fit well with Ford's manufacturing strategy, the fit has been increasingly poor in recent times.

This thesis describes and quantifies the nature of the poor fit between rail and Ford's new strategies, and discusses the use of a customer needs analysis to determine ways to improve this fit. The demands of lean production (in the form of the Ford Production System), synchronous production (in the form of In-Line Vehicle Sequencing), and environmentally friendly material handling are outlined in detail. The impact of each of these strategies on rail is also discussed.

Input from customers and users of rail transit is gathered through the use of a structured customer needs analysis, and is used to generate recommended modifications to rail equipment and logistics. The conclusion of this thesis is that the poor fit between rail and Ford's new strategies arises primarily from a failure to apply lean techniques such as process mapping and waste reduction to the rail system.

Thesis Supervisors: Daniel Whitney, Senior Research Scientist
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Acknowledgments

Completion of this research would not have been possible without the time and assistance of numerous employees of the Ford Motor Company. Specifically the guidance of Pam Stec, Jane Porterfield, and Bill Doman were greatly appreciated. Hayden Newell, Charlie Tucker, Tim Butt, and Scott MacGregor of the Norfolk Southern Railroad provided valuable first hand insights into the railroad industry.

Dan Whitney, Don Rosenfield, and Steve Eppinger provided insight and guidance in their roles as academic advisors. Their time and efforts are much appreciated. The Fellows of the Leaders for Manufacturing Class of 1997 have provided a continuous source of learning and insight before, during, and after this research took place.

The deepest thanks go to Bob, Sharon, and April Dever for their love and support, and for always sharing in the joys of learning.

The author wishes to thank the Leaders for Manufacturing Program for its support of this research.

Table of Figures

1. Introduction

1.1 The evolution of rail and the auto industry

Detroit is unique among American cities. A drive through the streets and along the highways of the Detroit metropolitan area leaves no doubt as to where the city got its nickname "The Motor City". Billboards advertise things like CAD/CAM systems, and rolled sheet steel. The streets have names like The Edsel Ford Freeway, The Chrysler Freeway, and the Reuther Freeway. The surrounding towns have names like Pontiac, Plymouth, and Cadillac. A 50 foot tire stands alongside the interstate with the tire manufacturer's name in white neon. As Robert Lacey puts it, "...This is the motor capital of the world. There are motor industries in Japan, Germany, Britain, in every industrialized country, but they are scattered. Nowhere else have the car makers all congregated in one single, grey, smokey location to build their cars together."[1]

It was not by coincidence that all of the US car manufacturers grew up and remain in southeastern Michigan. Before highways and extensive railroads, Detroit's location on the river between two of the great lakes made it easily accessible and attractive for industries which needed to ship material over long distances. During its early settlement, Michigan's forests provided abundant hardwood and her upper peninsula provided one of the largest iron ore deposits on earth.[2] The abundance of these two natural resources combined with the ease of shipping out of Detroit made the area a prime location for carriage builders to set up shop. Machining and metal working shops grew in Detroit as the need for parts for carriages, ships, railways, and a host of other industries grew. By the 1890s Detroit had all of the ingredients to become the motor capital of the word- skilled labor, natural resources, a good transportation system, and an existing "supply base".

As Ford enjoyed greater and greater success during the 1910s and 1920s, Henry Ford came to believe that his supply base was too widely dispersed. He envisioned an industrial complex which would take in sand, coal, and ore, and spit out finished vehicles. The Rouge was the realization of this vision, and is still in use today. This highly centralized complex includes a steel mill, a glass

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[1] Lacey, 1986 p. xiv
[2] Lacey, p 22

plant, a stamping plant, a frame plant, an engine plant, and an assembly plant. Such a structure inherently reduces the cost of transporting parts into the assembly plant, and thus the incentive to focus much management attention on inbound transportation.

It was a desire to reduce finished vehicle transportation costs which first led Ford to build remote assembly plants. During the days of the Model T all of Ford's plants were building variations of the same basic car. William Knudsen, one of Ford's top managers at the time, realized that it was cheaper and more efficient to ship parts of vehicles than to ship fully assembled cars[3]. This led to the construction of remote assembly plants. Kits of parts and partially assembled vehicles were shipped to these remote locations for assembly. The vehicles would then be sold in the region in which they were built. Rail provided a relatively inexpensive way to move large quantities of material over longer distances.

When General Motors introduced the idea of the annual model change, the nature of the US auto market began to change in ways that were to prove difficult for Ford to handle. As cars became more fashion items and less purely utilitarian, customers came to want a choice in their vehicles. It was no longer enough to have a sturdy, inexpensive Model T. A car company must now provide vehicles to suit different price ranges and different tastes. The number of models a car company produced grew, and the issue of plant complexity became of increasing importance.

In an effort to gain economies of scale within individual plants, and to reduce the complexity of the tooling in each plant, auto companies eventually segregated auto production by plants. Today most assembly plants make one or two vehicles, with the most complex of plants making seven different vehicles. Auto companies continued to build assembly plants in locations relatively far from Detroit to take advantage of local wage, tax, and other economic benefits. Component plants were built in remote locations as well. The end result of the segregation in plant production and the increased dispersion of plants was an increased requirement to transport both parts and finished vehicles over long distances.

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[3] Lacey, p 288

Not only were large in-transit inventories required to fill the transportation pipelines in a dispersed system, but large in-plant inventories were required to protect against variability in the transit times. In the 1950s and 1960s, inventory was viewed as a benefit. It protected against unreliable machinery, uncertain demand, and other variability including transit time variability. There was a greater focus on supplying demand than on controlling inventory costs, so carrying large inventories made sense.

During the 1970's and 1980's the US auto manufacturers increasingly lost market share and profits to overseas competitors. Oil crises shifted demand away from large, high margin vehicles to smaller, more fuel efficient, lower margin vehicles. Despite a long period of industry wide denial, the US auto companies came to realize that their competitors, particularly the Japanese, were doing business in a fundamentally different way.

In a book that changed the way many manufacturers viewed their business, Womack et.al. coined the term "lean" manufacturing. They talked of removing waste from the manufacturing process, and eliminating delays. Their work largely focused on improving operations within the walls of the plant. Minimizing inventory, pulling material through the production process instead of pushing it, and focusing on continuous improvement through employee involvement were cited as keys to being a successful manufacturer. Today, many US manufacturers, including Ford, are implementing ambitious programs to help make their plants lean.

What the Womack study did not really address was the issue of long distance transportation. The Japanese, who were the benchmark for the book, were described as having modeled their supply chains after Henry Ford's Rouge Complex. The idea was to locate suppliers and customers as close as possible to each other to eliminate the wasted time and movement of transporting goods over long distances. Unfortunately the US based operations within Ford had already invested significantly in a widely dispersed supply base. In a rush to adopt lean thinking on the plant floor the issue of how to make a dispersed supply network lean seemed to fall through the cracks.

The recent development of the Ford Production System, and an increased focus on total cost, are bringing supply chain leanness to the forefront. With this increased focus on the supply chain as a whole comes an increased focus on the logistics and equipment used to transport material through the supply chain into the assembly plants. What we find when examining transportation logistics and equipment is that there has been significantly more thought given to truck transportation than to rail. In part this is attributable to the nature of the truck and railroad industries and the competitive pressures each faces, and in part to deeply imbedded paradigms. What is clear is that rail as a mode of transit has not evolved fast enough to keep up with the evolution in Ford's manufacturing philosophy. The objective of this thesis is to examine why the logistics and equipment of the railroads are an increasingly poor fit to Ford's needs, and to determine ways for Ford to capitalize on the advantages of rail, while bettering rail's fit to current manufacturing strategies.

1.2 Thesis Structure and Preview

To better understand this idea of the poor fit between rail as a mode of transportation and Ford's new strategies we will begin with a brief description of how Ford came to view the fit with rail as poor, as well as a basic description of the terminology and nature of the rail system. We will then examine the specific elements of Ford's strategy which impact the appeal of rail as a mode of shipment. We will also examine how Ford makes the truck vs. rail decision, and how railroad companies view the auto parts business.

Once we have an understanding of Ford's high level strategic needs we will discuss the application of a customer needs analysis as a tool for determining ways to improve the fit between rail and the new strategies. We will see that this customer needs analysis indicated that the poor fit exists both in the areas of rail equipment and rail system logistics. Each of these areas will be discussed independently.

Regarding the logistics of the rail system, we will discuss three issues in depth: the process flows for material and box car movement through the rail system; the pricing structure of rail

transportation; and issues of rail fleet capacity planning. Regarding the issues of rail equipment, we will examine issues of equipment maintenance policies and the impact of creating unique equipment designs. We will discuss recommended changes to both equipment and logistics design, and reflect on the usefulness of applying a product design/customer needs analysis methodology to a project internal to a company.

2. Background

In this chapter we will begin by outlining how Ford came to view the fit between rail transit and new strategic initiatives as poor. Described below are the "symptoms" which led to the decision to investigate major changes to rail shipping. Before we begin a more detailed analysis of the problems of fit, we will briefly discuss the terminology and nature of the rail system and rail equipment. Also included in this chapter is a literature search to familiarize the reader with relevant research.

2.1 Poor "fit" between new strategies and rail shipment

As Ford moved to reduce inventories and make its plants more lean, more and more material was shipped into the assembly plants by trucks, and less by rail. This trend seemed to emerge as a result of individual plants and logistics planners making individual decisions, rather than as part of a stated strategy. Plants complained of poor delivery reliability from rail, of problems with the harshness of rail damaging parts in transit, and of problems with damaged or dangerous rail equipment. Logistics analysts were under pressure to reduce pipeline inventories, and rail could not offer the fast transits that truck could.

In the last six years 94 rail docks have been filled in in stamping and assembly plants alone.[4] The receiving capacity lost by these rail dock fill-ins must be made up in truck receiving docks. The shift from rail to truck was slowed by the plants' inability to add more truck docks. In some cases the entire perimeter of an assembly plant is now covered by truck docks. It is not unusual to see several hundred truck trailers parked on the grounds of some assembly plants, waiting to be unloaded. Clearly the problems rail presented could not be solved simply by eliminating inbound rail altogether.

In an effort to reduce direct labor costs, many jobs within Ford's plants have been automated. In the area of material handling, automated guided vehicles (AGVs) have replaced tug drivers, and automated material replenishment systems have reduced the demand for fork truck drivers. At last

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[4] Ed Dietrich Presentation, 11/96

count, 30% of the material handling labor in Ford's North American assembly plants was devoted to receiving material by rail and truck. Of this, 30% is devoted to receiving inbound rail, and the remainder is dedicated to unloading trucks.[5] Systems have been developed to automate the unloading of certain types of inbound truck loads, and are currently in use on selected commodities. At this time, the commodities that are automatically unloaded all arrive in homogeneous loads (i.e. a truck contains one and only one type of commodity) and all arrive in returnable containers, as opposed to cardboard boxes. There are no plants that automatically unload rail cars. This condition gave rise to the idea of reexamining box car design with the end goal of reducing labor costs through automation.

As inventories shrink, and synchronous material flow becomes a reality, the importance of reliable, on time delivery increases. Ford has expressed dissatisfaction with the quality of service from rail companies[6] and there is a feeling within Ford that the railroads are not as responsive to Ford's needs as many of the major trucking companies. Ford has also complained that not only are rail delivery times unreliable, but the transit time is excessive. The length of time it takes to move empty racks back from an assembly plant to a supplier plant is often more than twice the length of time required to move the full racks from the supplier to the assembly plant. This increases the amount of money Ford must invest in shipping containers (i.e. racks and packaging materials) to fill the transit pipeline in both directions. These conditions together indicate the need to examine the logistics of the rail system and determine how to make a better fit between the logistics Ford envisions for a lean supply chain and the services the rail companies can provide.

Before we examine the issues noted above in more detail, it is useful to spend some time understanding the basic nature and operation of rail shipment and the related equipment.

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[5] 1992 Frank Payne material handling labor study. Spot verified and corrected to 1996 levels.
[6] Ed Dietrich Presentation 11/96

2.2 Box car basics

Although it is not at all unusual to see rail tracks, rail yards, and locomotives in many towns and cities, the nature of rail shipping remains a mystery to many. What follows is a very brief overview of how the US rail shipping system works, and some of the related terminology.

There are two basic types of trains in the US rail system- passenger and freight. Each has one or multiple locomotives pulling a number of "cars" behind it. In passenger trains these cars are typically air conditioned, lighted, heated, and well cushioned. In freight trains these cars may be anything from a box on wheels to a pressure tanker. An increasing segment of rail transport involves "intermodal" shipments. In such shipments a container may spend some time attached to a rail car, some time stacked on a boat, and some time being pulled behind a tractor trailer. For the purposes of this paper we will focus on box cars. A box car is a relatively generic rail car, that functions as a large box on wheels. The sizes of today's box cars range from 50 feet long, 9 feet wide, and 10.5 feet high, to 86.5 feet long, 9 feet wide, and 12.75 feet high. These cars typically have sliding doors on both sides in the center of the car.

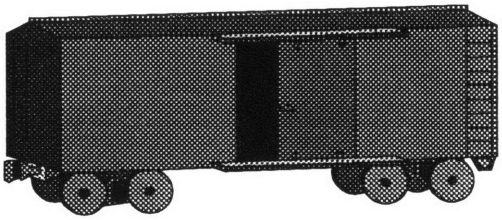

Figure 2-a - A typical Box Car

Within the interior of the car there maybe dividers or load restraint devices which restrict the movement of goods within the car. The two most common type of load restraints are bulkheads and column load dividers. A bulkhead is a large panel that spans the cross section of the car. Moveable bulkheads are typically hung from rollers in tracks along the ceiling of the car and can be positioned anywhere along the length of the car. Column load dividers (CLDs) are essentially I-beams hung from rollers in the intersection of the ceiling and side walls. These beams can be positioned anywhere along the length of the car and locked into place. For safety reasons, Ford no longer employs moveable bulkheads in any of its box cars.

Typical box cars have two sets of wheels each containing two axles. These axles are held together by a device called a "truck". The truck mounts to the axles, contains the springs which cushion

the ride, and mates to the underside of the box car via a shallow bowl. Because the wheels on a box car are rigidly coupled to the axle, there is no differential in speed of the wheels when rounding a curve. Were rail wheels flat, there would be slippage of one or both wheels along the track when navigating a curve. To avoid this condition, rail wheels are designed with a taper. The diameter of a rail wheel increases from the outboard side of the wheel to the inboard side. Thus when navigating a turn, the wheels on a train will shift towards the outside of the turn. This changes the effective diameter of each wheel. The outside wheel in the turn is riding on its inboard edge, where the diameter is larger, and the inside wheel is riding on its outboard edge, where the diameter is smaller.

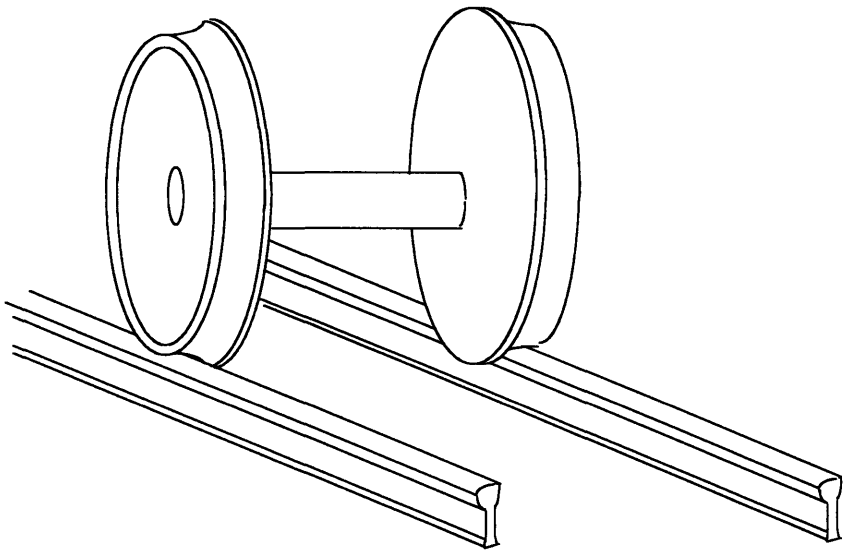

Figure 2-b Rail Wheels and Axle

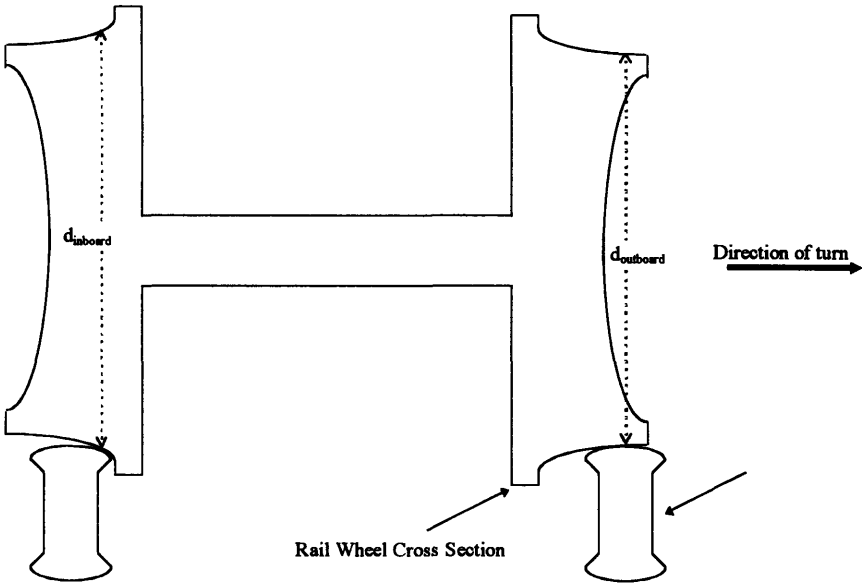

Figure 2-c Differential action around a curve

From the figure above it is clear that a set of rail wheels can move in a direction perpendicular to the direction of train travel. If this happens during a straight, flat section of rail it will cause the axle to tip slightly to one side or the other. Because of the profile of the rail wheels, they will naturally tend to want to "correct" this offset condition. This can lead to a repeated rocking back and forth of the rail axles known as truck hunting. Truck hunting causes oscillations of the box car which may be damaging to loads, and in severe cases can cause derailments.

The loads contained within a box car can also be damaged by forces exerted on the end of the car. The process of coupling two box cars together is not a gentle one. One box car, the target, remains stationary while a second one is rolled into it. This impact causes a coupling between the two cars to engage. In many box cars the couplings have a hydraulic cushioning cylinder to reduce the forces transmitted during this impact. In theory the maximum speed at which this coupling can occur is 4 mph, but in practice this is difficult to monitor on a constant basis.

Both the cushioning unit and the coupler can be compressed and extended so that the total travel between two attached cars may exceed 20 inches. This implies that when a long string of coupled box cars is pulled by a locomotive, there is some "slack" in the train. Under acceleration this slack is used up. As each coupling unit reaches its full extension there is a shock transmitted to the box

cars it connects. The same is true as the couplings are compressed (when a train is pushed, or is going down a hill slowly for instance). The forces generated by this process are called slack action and are thought to contribute significantly to damage to rail goods.

2.3 Rail network basics

Perhaps the simplest way to visualize the rail system is as a large number of nodes with paths between those nodes. There are terminal nodes where a rail line ends (places like plants that ship by rail, end-of-line stations for passenger rail, and rail service yards) and intermediate nodes through which rail lines pass (like "switching yards" and the station stops along a passenger rail route). Transport by rail involves navigating from the origin node to the destination node. Good transport by rail means doing this in a time and cost effective manner.

A typical rail route may involve travel along many different paths through the system. Not all parts traveling on a path are headed for the same destination, nor do they share the same origin. A train traveling from Detroit to Chicago may contain parts from a supplier in New Jersey to a customer in California, as well as from a supplier in Buffalo to a customer in Chicago. This implies that a train arriving at an intermediate node will need to be disassembled so that the individual cars can be sent to the next node on their path. A node where this takes place is known as a switching or classification yard. Literally "switching" a car means moving it from one track to another. Colloquially switching can refer to any rearranging of cars. Switching a plant involves removing the box cars from that plant and replacing them with different ones.

When a series of box cars are assembled into a train in a switching yard, the order in which the cars are connected is described as the blocking of the train. A well blocked train will have all of the cars going to one destination kept together in the line of cars. A poorly blocked train may have all of the cars going to one destination scattered throughout the train. How well a train is blocked affects how long it takes to switch that train.

The average one way rail journey in Ford service is 514 miles and takes 4.2 days. A journey may take a car directly from origin to destination, or may require several switches along the way. Plants that ship a large volume of material by rail may be switched as often as five times per day. Plants that ship very little by rail may only be switched once every other day. There are currently 7693 rail cars assigned to Ford service. Of these the vast majority (5974) are 86 foot long high cube cars. These are primarily used to carry metal stampings, but also can carry plastic components such as fascias and fuel tanks. Of the remaining cars, 1014 are 60 foot cars which primarily carry powertrain components, and 705 are frame cars which carry frames for trucks and non-unibody cars.

2.4 Literature survey

Upon concluding a literature search for information on railroad equipment and logistics design, one might think that all US railroads went out of business in the early 1960s. Many of the books and articles dealing with the railroads were written before 1900, and very few after 1975. In 1980 the US railroad industry was deregulated in the Staggers Act, but even this development received relatively little treatment in the literature. The existing post-1960 literature breaks down into four major categories: the rail business and service environment, design and modeling of rail logistics systems, innovations in rail equipment, and the engineering and physics of rail transport.

In a Transportation Research Board Conference Address Martland, Little, and Sussman[7] discuss providing reliable service to different rail traffic classes. They argue that the definition of "reliable" service depends upon certain characteristics of the commodity being transported. They also analyze the major causes of variability or unreliability in rail transport. In a similar article written 18 years prior to Martland, Stenger and Beier[8] describe ways for the railroads to more effectively market their services. They advocate a customer needs driven marketing approach

[7] Martland, Little, Sussman 1994
[8] Steiger and Beier, 1976

where the railroads assume greater roles as "logistics providers". Gary Draper[9] discusses rail (and other modes of shipment) from an oil and chemical company's point of view. He offers suggestions for how to take advantage of the changes (including deregulation) within both the rail and trucking industries. In a Transportation Quarterly article, Delaney[10] describes how better service from transportation and logistics providers has enabled a reduction in total US inventories and decreased order lead times. He also notes that the rail industry increased return on investment in an era of decreasing unit revenues.

For reasons we will discuss later the optimization of rail logistics is a complex problem. Models exist for optimizing simplified models of a rail network, or for optimizing service as measure by a simplified set of metrics. Marin and Salmeron[11] describe exact and heuristic methods for designing rail freight networks. The objective function is total cost, including the operating costs of moving the freight, the logistics costs of reclassifying the freight at intermediate yards, and the investment cost of required additional capacity. Harker and Hong outline a pricing scheme that would price the resource of "use of existing rail track" using a market-like approach. Their argument is that the total rail system in the US is operated sub-optimally because each railroad is trying to maximize profit over its own sections of track without regards to the whole system. They advocate applying game theory to determine the prices for track usage that would result in the determination of more optimal train schedules.

Although equipment innovations are relatively rare in the railroad shipping industry, the literature reflects the occasional innovation. Many "railroad" equipment innovations deal with transporting containerized freight or over-the-road trailers by rail. What is most striking about the "innovations" described in various conference proceedings is that the same features are listed as innovations year after year. One gets the impression that new rail equipment designs are not widely circulated in the industry. The proceedings from the ASME in 1980[12] regarding "Progress in railway mechanical engineering" claim that there is "renewed concentration on design for

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[9] Draper, 1986
[10] Delaney, 1991
[11] Marin and Salmon, 1996
[12] ASME "Progress in Railway Mechaical Engineering"

commodities other than coal". The article continues on to cite innovations in intermodal service, including the concept of a "road-railer", or an over the road trailer that can run on rail tracks. Other innovations include a variety of improved hopper cars, tanker cars, and covered steel coil cars. The proceedings from the 1994 International Mechanical Engineering Congress and Exposition include a review of "Progress in railroad freight car engineering". [13] It is interesting to note that nearly all of the progress came in the area of intermodal equipment, including a covered steel coil car and an over the road trailer capable of riding on rail track. There were no advances to box cars, or major box car components. In Europe, a similar conference in 1990 yielded designs for improved intermodal service similar to those in the 1980 ASME and 1994 IMEC proceedings.[14] Included in the European review were new methods of placing over the road trailers directly on rail track.

Numerous articles deal with the physics of rail transportation. Treatments of the subject range from highly sophisticated computer models of rail equipment dynamics to flaws with current equipment specifications. Bhatti and Garg[15] provide a very readable discussion of rail dynamics, as well as a good introduction to the associated terminology. Discussions of the design and performance of specific rail car components can be found for components ranging from bulkheads[16] to the springs and axles for special purpose rail cars.[17] Scales[18]presents a good discussion of the dynamics within a train during impacts and travel.

In this chapter we have come to understand how the poor fit between rail as a mode of parts shipment and Ford's new strategies became apparent. The move from rail to truck was slowed only by the physical limitations of installing new truck docks in assembly plants. Fear of increasing labor costs gave rise to consideration of new rail equipment designs. Rail delivery reliability and

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[13] Punwami, 1994
[14] Etwell, 1990
[15] Bhatti and Garg, 1984
[16] Leedham, Sfirakis, and Spearin, 1993
[17] Singh, Irani, Punwani
[18] Scales, 1984

transit duration became more pressing issues as lean manufacturing and tighter cost targets became realities. Having armed ourselves with a basic understanding of rail logistics and equipment we must now turn our attention to understanding the specific needs of Ford's new strategies and the implications of these needs for rail.

3. Ford's Strategic Direction and the Future of Rail

In this chapter we will attempt to answer three questions: How are Ford's strategic initiatives changing the demands on rail service, how do the railroads view their auto parts business, and how is Ford's truck vs. rail decision making process equipped to deal with the changes in Ford's needs and the railroads changing services?

3.1 Why is Ford changing the way things are done?

At a high level, Ford's strategic objectives address the basic issues of cost, quality, and timing. Cost and quality are relatively unambiguous terms, but timing can mean different things at different times. For the purposes of this study, we will look at issues of timing as they pertain to material delivery and movement through the factory. Let us examine the three strategies which most greatly impact the appeal of rail as a mode of shipping, and see how each strategy addresses the issues of cost, quality and timing.

3.1.1 Ford Production System

In 1995 roll-out began of the Ford Production System. This system, known internally as FPS, was designed to remove waste from Ford's manufacturing and distribution operations. The system was inspired by Toyota's success in gaining market share, improving quality, and reducing costs through the use of the Toyota Production System. The Ford Production System addresses issues of effective work groups, defect elimination, capacity optimization, production throughput optimization, and total cost. FPS metrics extend beyond the plant floor to measure performance of the entire supply chain at achieving lean production. FPS metrics have implications for the fit of rail as a mode of shipping in all three areas we are examining- cost, quality and timing.

<u>Cost: Minimize total per unit cost</u>. In the past, Ford has emphasized labor and overhead as plant cost metrics. FPS aims to broaden the cost perspective to include all inputs to the delivered cost of a vehicle. The total cost includes not only materials, labor, and overhead, but transportation, facilities, inventory, salaried support, and any other contributing component. Rail offers both advantages and disadvantages in terms of cost per unit. The cost per ton-mile of rail is typically lower than by truck for longer distance moves, but the typical amount of in-transit inventory is

greater. We will discuss more about the rail cost structure in a later chapter. For the time being, we should note that FPS increases the focus on transportation, inventory, and logistics costs.

Quality: Zero Defects/Zero Waste. FPS sets a stretch objective of zero defects, or a 100% first time through capability. Clearly defect reduction is required if total costs are to be reduced, but there is a more serious effect of defects in a lean system than merely the cost of bad parts. As inventories are reduced, defects are more quickly passed on to subsequent operations. Any defects passed on to an assembly plant can halt production and cause profit losses on the order of millions of dollars per day of lost production.

Not only must supplier production processes produce zero defects, the shipping of parts must not cause any damage. Rail shipping is widely perceived as a "rough" mode of shipment, which causes significant material and shipping container damage. For the period from 9/94 to 7/96 Ford filed over $3.5 million in damaged material claims against its major rail suppliers.[19] This number likely under-represents the actual value of material damaged by rail because of the difficulty of actually filing a damage claim. If rail is to be a significant mode of transit in the future, part damage must clearly be reduced in a total cost effective manner. This has implications for the design of shipping containers, rail cars themselves, and for the logistics of moving material by rail.

Timing (1):Reduction of order to delivery time for components. Ford has made the decision that there should be no more than six days between the time an assembly plant places an order for a part and the time that part leaves the assembly plant on a finished vehicle

[19] McKessan Damage Claims report

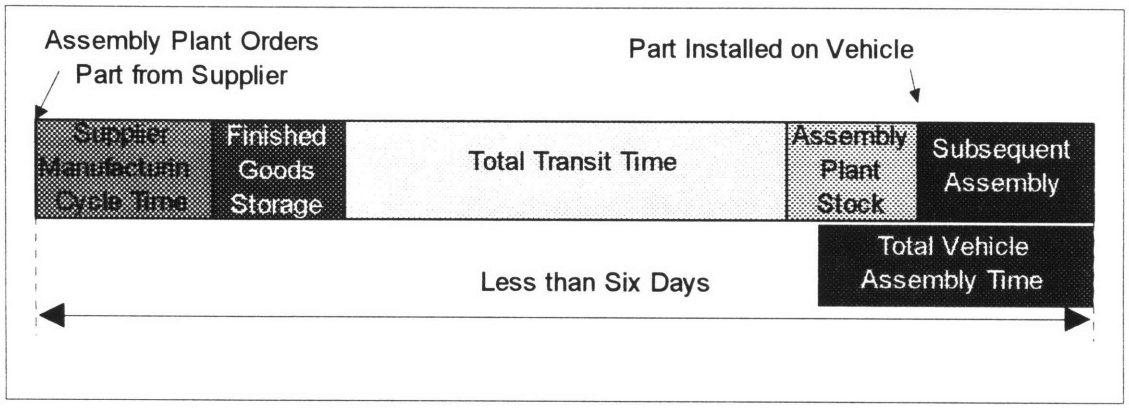

Figure 3-a- Order to Delivery window

$$\text{TransitTime} \leq 6 - \text{SupplierMCT} - \text{FinishedGoods} - \text{AssemblyPlantStock} - \text{SubsequentAssembly}$$

Equation 3-a Maximum transit time as allowed by FPS

If rail is to be a viable mode of transit, the transit time must be reduced as per Equation 3-a. Figure 3-b shows the distribution of one way rail transit times for all routes in Ford's rail system. Of the 275 origin-destination pairs in Ford's rail system, 46 have one way transit times of greater than six days. Clearly all routes with one way transits greater than 6 days will not satisfy Equation 3-a. Many of the routes with transit times of 3-5 days may not satisfy this equation depending on the manufacturing cycle times of the components being shipped, and the installation location along the assembly line. In a presentation to Ford's major rail transportation suppliers, FPS representatives set a "stretch objective" of 24 hour delivery between any two rail locations in North America. This goal is based on current levels for supplier manufacturing cycle times, finished goods inventories, and assembly plant stocks.[20] The longest non-Mexican route in Ford's North American rail system is from the Budd Company's Philadelphia plant to Ford's Kansas City Assembly Plant. This route is 1126 miles and currently takes 6 days one way. To meet the FPS stretch objective the train from Philadelphia to Kansas city would have to average more than 47 miles per hour. The fastest train in the Ford system today covers 580 miles in one day, roughly

[20] DeMuro/Dietrich

than half of the distance that the Philadelphia-Kansas City train would need to cover in the same period of time.

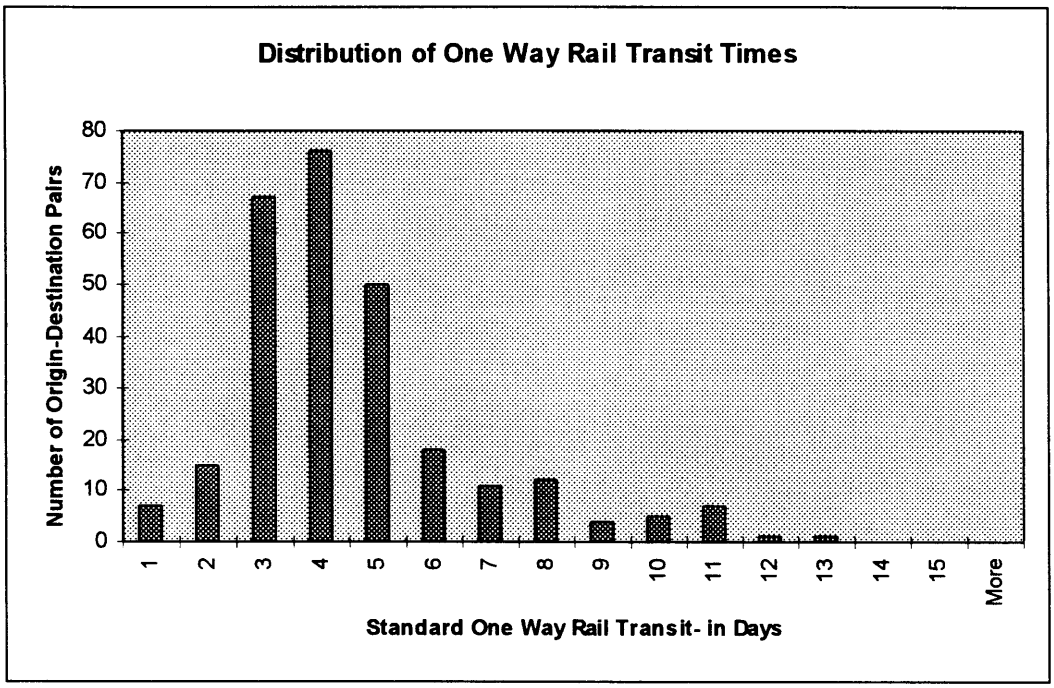

Figure 3-b Distribution of One Way Standard Rail Transit Times

Timing (2): Reduction of delivery time window to +/- 15 minutes. FPS requires that all material arrive within 15 minutes of the scheduled arrival time. Current rail on-time statistics vary significantly by plant and by rail line, but in many locations rail does not perform at the level required by FPS. For example, the Twin Cities assembly plant measures on time performance as delivery no more than 24 hours past the scheduled delivery time, and has an average on time rail performance of less than 85%. For all of Norfolk Southern's Ford routes the on time performance (where on time is defined as less than 4 hours late) averages between 95% and 97%.

3.1.2 ILVS

The 6 day order to delivery window outlined in FPS assumes that there is a corresponding 6 day fixed, level, and sequenced schedule. This concept is what Ford refers to as In Line Vehicle Sequencing. The vision for ILVS is as follows: Dealers place orders for vehicles beginning four weeks before the date the vehicle will be built. As the build date nears, the orders are fitted into a

production sequence which is leveled for mix options.[21] Six days before the build date, the production sequence is locked in, and parts orders are sent to suppliers. Suppliers then manufacture and ship the required parts in the sequence they will be installed on vehicles.

ILVS has different implications for different levels of complexity. For example, parts with low complexity and low storage costs are unlikely to be sequenced. A simple example of this is fasteners. If there are two types of screws in a particular application and a small box holds thirty days worth of screws, it would be unwise to provide the operator with a "sequenced stream" of screws. Rather, two boxes of screws are placed at the line side, and the operator simply picks from the appropriate box. Error-proofing techniques can be used to prevent installation of the wrong screw. For parts with high complexity and high storage costs, such as instrument panels, sequencing can yield a lower total cost. Ford has not yet established specific guidelines for determining which parts will be sequenced. Nonetheless, rail presents a number of difficulties in implementing ILVS for sequenced parts, all related to the issue of timing.

Timing (1) Excessive transit time: As discussed above, many rail transit times will exceed the order to delivery window. The negative impacts of unreliable rail delivery are much worse in an ILVS system. Under the current operating conditions, if a rail car is delayed in transit, the rail carrier will often expedite a different rail car containing the same commodities to meet customer demand. In an ILVS system where parts are identified to match up to specific vehicles, this type of expediting will no longer suffice.

Timing (2) Sequence integrity: Managing a sequenced stream of incoming parts is somewhat problematic in rail as opposed to truck due to conveyance layout. Because a trailer has one door on the end of the trailer, parts are unloaded in the reverse sequence of which they were loaded. This facilitates the unloading of sequenced parts in the assembly plants. For example, finished seat

[21] Leveling involves distributing option features evenly throughout the production sequence. For example a production sequence that called for 40 vehicles with sunroofs to be produced in a row might strain the resources of the sunroof installation portion of the assembly line. A level production mix would spread vehicles with sunroofs throughout the production mix.

kits are shipped in sequence to assembly plants on specially equipped trucks. The seats are loaded into the trucks in reverse sequence order, and roll off in sequence at the assembly plant.

The unloading of rail cars in sequence requires additional decision making because the doors to the rail cars are located in the center of the cars. When an operator opens a rail car door he will typically be facing 4-12 racks which he can unload in stacks of 1, 2, or 3 high. He must decide which stack to unload first, whether to destack the load before or after unloading it, and which side of the car to unload once the racks in the doorway are removed. Rail cars are bi-directional, and may get turned around several times during their transit. This implies that the side of the rail car facing the loading dock may be different at the assembly plant than at the supplier plant, and that there is no "front" of the car. Thus unloading a rail car in the reverse sequence from which it was loaded is a more complicated problem than unloading a sequenced truck. Current rail operating conditions would require a staging area where the racks from a rail car could be sorted into their appropriate sequence.

3.1.3 Greening

One of the key elements of the seven major strategies underlying Ford 2000 is to "Lead in Corporate Citizenship". Among other things, this strategy requires attention to the environmental impacts of Ford's decisions. Since over 50% of the waste from Ford manufacturing plants is non-returnable packaging materials[22], reducing the packaging waste stream is a major part of leading in corporate citizenship. Reducing the packaging waste stream will also help meet increasing legislative demands governing manufacturing waste generation and disposal. The most obvious way to reduce the packaging waste stream is to eliminate disposable packaging. Unless Ford learns to design parts that don't need protective packaging, this will mean using more returnable shipping containers and packaging materials.

<u>Cost: Increased requirement for return transportation of empty shipping containers.</u> The current pricing structure of rail is based on round trip transportation, whereas the truck pricing structure is based on one way pricing. This means that if a commodity is currently shipped by truck in

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[22] Packaging Waste Stream Elimination Strategy Report, May 1996

disposable packaging, and greening requires a shift to a returnable container, the transportation cost for the commodity doubles.[23] This gives rail a greater cost advantage for returnable containers than for disposable ones.

Although the pricing structure of rail is favorable in terms of transportation cost for returnable containers, the rack investment costs required to ship by rail are higher. Not only is rail typically a slower way to ship goods than truck, the return transits for empty racks shipped by rail are longer than the loaded transit time. For the 30 day period ending October 3, 1996 the average return transit time to a Ford stamping plant was 2.34 times as long as the transit from the stamping plant to the assembly plant. This implies that more racks must be purchased to fill a rail pipeline than a truck pipeline. Looking at the October 1996 data and weighting the outbound vs. inbound transit difference for volumes along each route, we find that the excess outbound transportation time causes a 40% increase in the required number of racks to stock the transit pipeline.[24] (This figure of 40% weights delays by the number of box cars affected. For example a delay of ten box cars for one day is ten times as bad as a delay of one box car for one day.)

In addition to the cost of purchasing additional racks to fill the rail pipeline, Ford incurs the cost of tracking these racks through the entire transportation system and of redistributing common or shared racks as needed among supplier plants. Ford is currently examining strategies for container control, including the possibility of a supplier managed container system. Although it is not clear who will pay to implement and manage a container control system, these costs will eventually flow back to Ford in one way or another.

Quality: Required level of part protection. As discussed earlier, rail transit has the potential to transmit significant forces to the loads being transported. Rail shipping racks are designed to withstand these greater forces. This means building heavier, sturdier racks. Not only do heavier and sturdier racks cost more in material required to fabricate, but the fuel consumed by

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[23] This assumes a 1:1 loaded to empty container ratio. Some returnable containers can be collapsed when empty, so the increase in transportation cost is less than simply doubling the one way transit.

[24] Assumes that rack investment to fill the pipeline is proportional to the number of box cars required to fill the pipeline.

transporting the rack along its route for many years represents a life cycle cost. Because FPS requires parts not be damaged in transit, rack designs are likely to become even more costly to provide the required protection.

Not only are the racks themselves likely to become more expensive, but there is a risk of a decreased packaging density. To prevent material damage, greater inter-part spacing may be required in packaging. If the packaging density is reduced, more racks or larger racks will be required to ship the required volumes. Although there are no current indications of a trend towards decreased packaging density at Ford, there are such indications at one of Ford's competitors. Increased product quality requirements have decreased packaging density, and some moves have been shifted from truck to rail because of this.[25] There is a risk that as FPS demands zero transit related damage Ford may opt to decrease packaging density to reduce the risk of part to part contact.

Timing: Incentives to reduce return transit pipeline. As more material is shipped in returnable containers, the amount of capital tied up in racks increases. If the return transit time continues to significantly exceed the loaded transit time, rail companies will see increasing pressure to bring the two transit times into line. As described above, reducing return transit times to the same level as loaded transits could translate into a reduction of as much as 40% in rack investment.

Ford's guidelines for the design of returnable containers aim to reduce the amount of material shipped in a returnable container to one day's worth or less. This has similar implications as reducing the packaging density. Because the cost of ten containers, each measuring one cubic foot, is likely to be greater than the cost of one container, measuring ten cubic feet, this guideline will increase container investment in some cases. This increase in container cost will drive a reduction in the return transit time.

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[25] 6/14/96 Competitor interview

Finally, as more returnable containers are put into use the delivery accuracy and reliability of container return will become more important. If the container system becomes truly lean, the impact of a late delivery of containers or a mislabeled shipment of containers becomes more serious. Current practices are not highly reliable when it comes to accurately identifying box car contents, particularly for shipments of empty containers.

3.2 "What we think about auto parts cars"- The railroad perspective on fit

The issue of "fit" needs to be examined not only from the point of view of Ford as a customer of rail shipping, but from the point of view of the railroads as well. First we need to understand the percentage of total revenue railroads derive from automotive related transportation. Then we need to compare the demands of handling auto parts with other commodities shipped by rail. Finally we need to understand how the railroads view the competitive market in which they operate.

Railway Operating Revenues by Market Group for Norfolk Southern

	1995	1994	1993
Coal	$1,240.3	$1,262.5	$1,213.3
Paper/Forest	$519.8	$505.4	$502.7
Chemicals	$513.5	$512.2	$472.9
Automotive	$454.1	$432.1	$429.5
Agriculture	$359.0	$347.5	$319.7
Metals/Construction	$339.5	$321.4	$296.1
Intermodal	$470.5	$425.6	$390.2
Total	**$3,896.7**	**$3,806.7**	**$3,624.4**

From 1995 Financial statements

Figure 3-c Railway Revenue Distribution

Figure 3-c shows the distribution of revenues for the Norfolk Southern railroad. Note that revenues from automotive business are only 11.6% of total rail revenues.[26] The heading "Automotive" includes not only parts shipments from suppliers to assembly plants, but finished

[26] For the rail industry as a whole auto related transportation represents 5.87% of total revenue (Logistics Management, January 1997)

vehicles as well. NS ships finished vehicles for 16 vehicle manufacturers, but parts for only the Big Three.[27] This implies that the total percentage of revenue derived from auto parts shipment is very small, and the incentives for NS to devote significant management attention to auto parts are small.

Figure 3-c also shows that the largest source of railway revenue is coal shipping, and the fastest growing segment is intermodal. Shipping coal demands a very different set of management priorities than shipping auto parts. Coal is most often shipped in dedicated trains (100 or more identical cars filled with coal). Because of the low value per ton of coal, inventory costs are much less for a coal train than for a similarly sized load of auto parts. Coal can not be damaged significantly by a harsh ride, and requires no protection from the elements. Coal deliveries are not typically made on a just in time basis, so delivery reliability is not as crucial as for auto parts. The manager of a railroad control center, which tracks rail cars and their contents during shipment, commented, "We pay more attention to Ford's parts cars that to anything else"[28]. When compared to coal, auto parts seem to be a more difficult way to earn a smaller percentage of total revenue.

Despite the seeming un-appeal of devoting resources to auto parts business, NS continues to make notable efforts to retain this business. As Ford and other manufacturers move towards a smaller supply base, NS and other railroads may risk losing the profitable finished vehicle business if they do not provide quality auto parts service as well. In attempts to assist Ford in better managing material distribution, NS encourages Ford to make use of the growing intermodal transportation options available.

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[27] NS ships finished vehicles for BMW, Chrysler, Ford, GM, Honda, Isuzu, Jaguar, Land Rover, Mazda, Mitsubishi, Nissan, Saab, Subaru, Suzuki, Toyota, and Volkswagen.
[28] 6/18/96 Virginia Control Center

3.3 The truck vs. rail decision making process

3.3.1 Conventional Wisdom

The existing rail paradigm within Ford claims that rail is effective for parts shipped in returnable containers, in large volumes over long distances, while shorter routes and smaller volumes are appropriate for trucks. This paradigm is based on four interrelated characteristics of rail shipment: the "set up to run time" ratio, the volumetric shipping quantities, the cost per mile, and the pricing structure.

To borrow production terminology, rail transit has a very high "set up to run time" ratio relative to truck transit. In this analogy, switching cars, blocking trains, and waiting for connections are the "set-ups", and actually moving along the rail lines is the "run time". Not only are the set up times high in relation to the run times, but they do not scale (i.e. they have a large fixed component). The time between switches and the time a load spends waiting for a connection are independent of the length of the total trip. In cases where the distance to be traveled is "small", a truck can often complete the trip from supplier to customer before a rail car would have been switched out of the plant and made its mainline connection. In the current rail paradigm, "small" seems to be less that 250-300 miles. Of the 275 routes in Ford's system, only 31 are less than 250 miles long, and 14 are between 250 and 300 miles long.[29] Both FPS and ILVS demand shorter transit times with more reliable delivery windows. The current rail paradigm indicates that on both these counts over-the-road trailers seem better suited to Ford's new manufacturing strategy.

Although the "set up to run time" is high, rail has the advantage of a lower cost per ton-mile in nearly all routes than truck.[30] Because of the nature of rail shipping, the variable costs such as labor and fuel can be spread out over a larger base than in over the road trailers. A typical train might consist of a locomotive pulling 100 or more cars, with a three or four member crew that can run 24 hours a day. To move the equivalent amount of material in trucks would take at least

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[29] INTRAN standard route length for all routes in 1997 Car Report

[30] With the exception of very short routes, the transportation cost of shipping a given load by rail will almost always be less than of shipping the same load by truck.

300 trailers, each with a two man crew for 24 hour operation. As affordable business targets drive costs in all areas down, rail becomes a more attractive mode of shipping.

The cubic capacity of an 86 foot long standard box car is 10,110 ft^3. The cubic capacity of a 53 foot long over the road trailer is 3147 ft^3 . Because of differences in the shapes of shipping racks, it often takes 4-6 over the road trailers to convey the same material as one rail car. This implies that rail is better suited to high volumetric shipping quantities. Larger parts required in high volumes are typical candidates for rail shipment. Stampings are a good example of parts that are shipped by rail even over relatively short distances due to their high cubic volume. Because FPS requires smaller batch sizes, this aspect of rail shipment will encourage some parts to be shipped by truck instead of rail.

Finally, the historical pricing structures for rail and truck differ in one key way- rail is priced round trip, whereas truck is priced one way. For goods shipped in returnable containers, the cost per round trip mile advantage of rail is even greater. As Ford ships more material in returnable containers, this aspect of the rail pricing structure will make rail a more attractive mode of shipping.

3.3.2 Description from ISO 9000 Documentation

According to Ford's logistics analysts the primary determinant of the transportation mode for a given commodity is history. The mode of shipment will typically not change from rail to truck or vice versa unless a new supplier is sourced. Requests for mode changes will be entertained when a plant involved presents a compelling reason for the change. For example, manufacturing engineers requested that headliners be shipped by truck rather than rail due to a history of transit related damage and the mode for this move was changed. This implies that the modes of shipping currently in use may not be optimally suited for Ford's new manufacturing strategy. As Ford changes the way it manages the supply chain, the truck vs. Rail decision making process must change accordingly. We will look at how the mode decision is currently made within Ford, and compare that with the new supply chain strategies. We will also examine how a competitor makes mode decisions, and what we can learn from this.

Interviews with Ford logistics planners indicated that there is not one single format used by all analysts to make the truck versus rail decision, but that the ISO9000 documentation outlines the general approach taken by all analysts. The ISO documentation includes outlines of the decision making processes for the establishment of a new move, the calculation of the required number of rail cars to service a given origin, and the calculation of logistics costs before and after a change to packaging, mode, daily volumes, etc.

Figure 3-d and Figure 3-e below depict the truck vs. rail decision making process for two separate cases. The first depicts what a logistics analyst is supposed to do when some feature of a move has changed. This might include increased volume along the route, a change in supplier, or a change in packaging. The second deals with the truck vs. rail decision for a new move of powertrain components. These processes illustrate the decision making guide found in the ISO9000 documentation; the ISO documents themselves do not contain process flows.

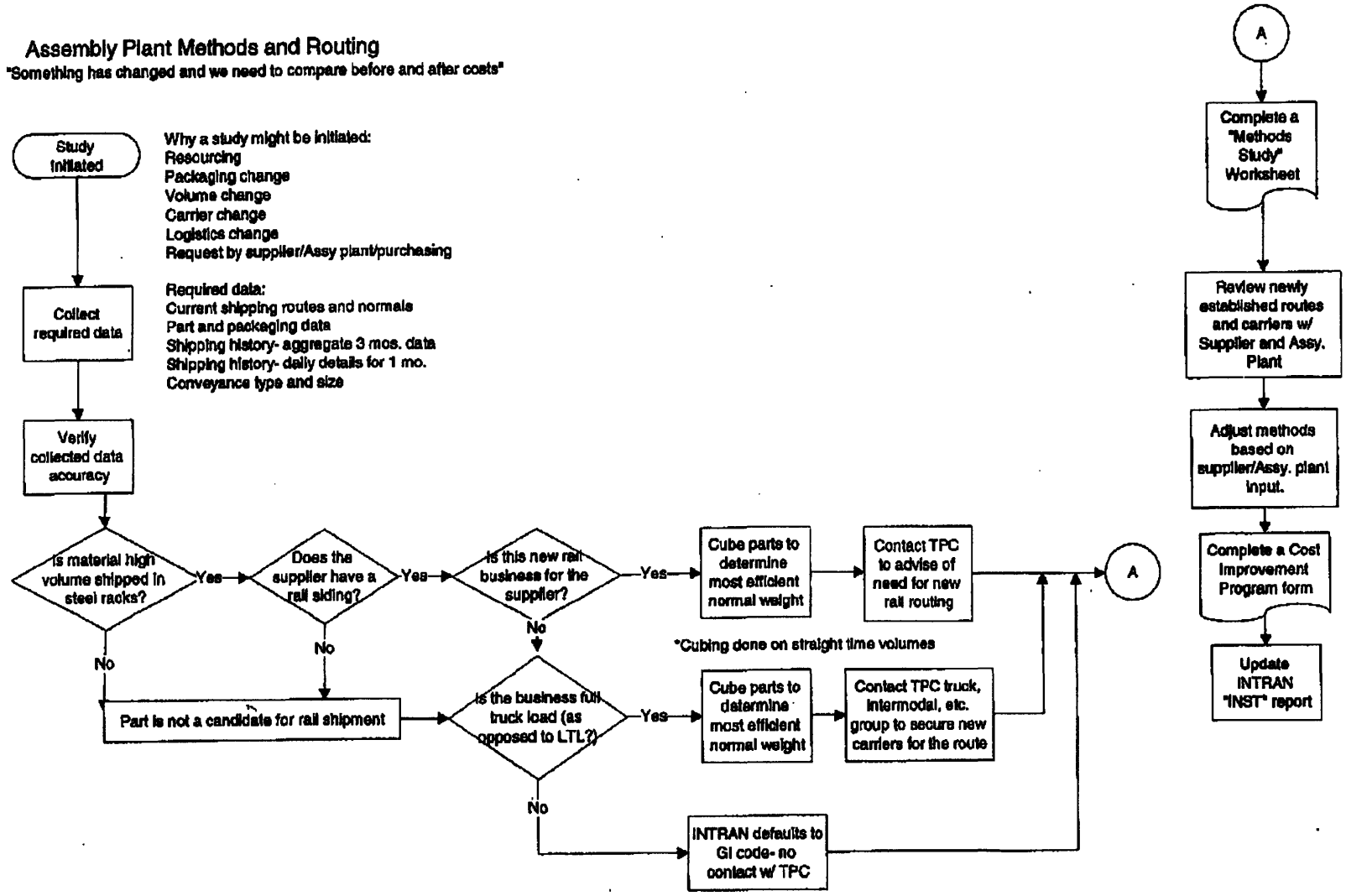

Figure 3-d Assembly Plant Methods and Routing Study

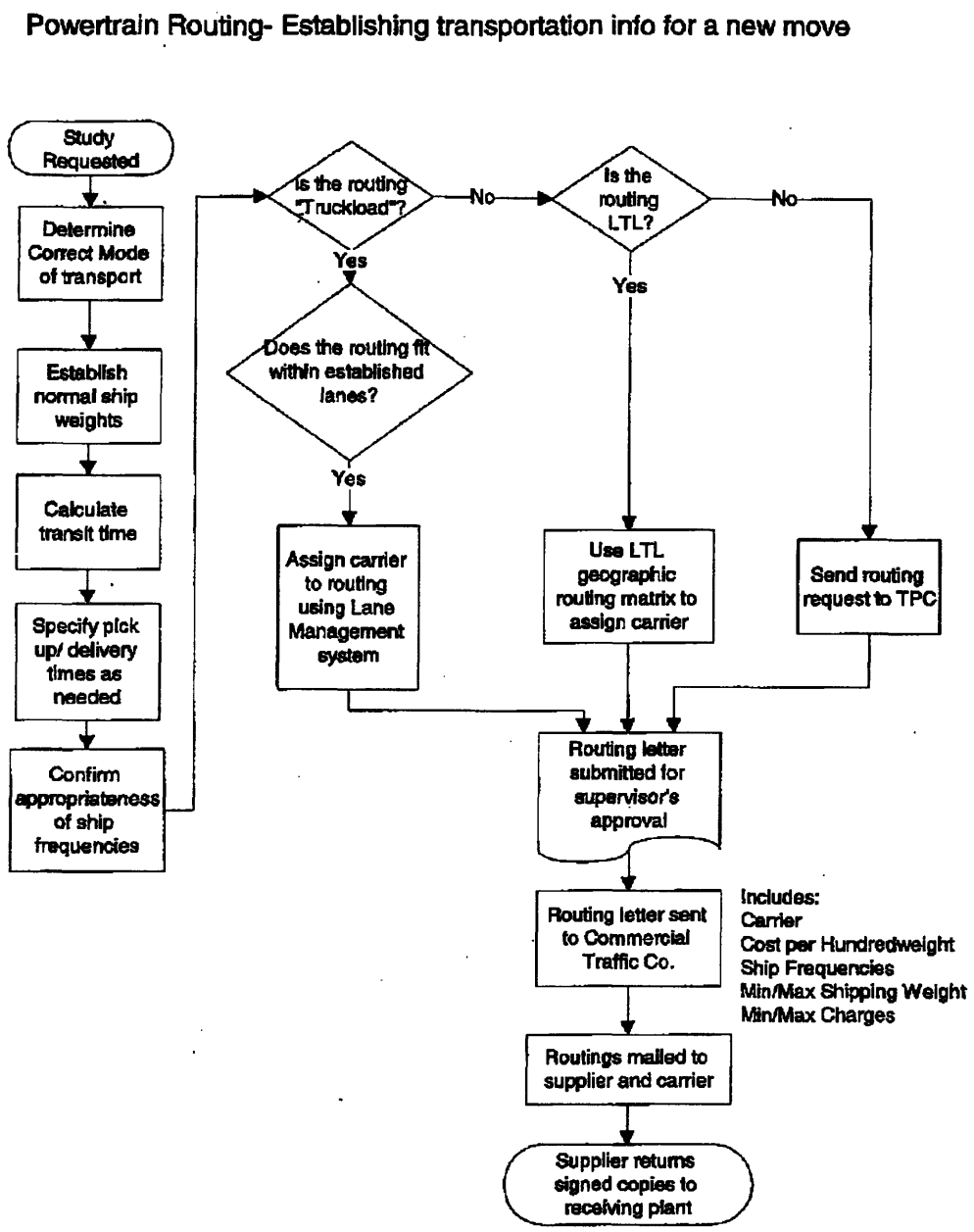

Figure 3-e Powertrain Routing Study Instructions

The salient feature of these decision making processes is the lack of detail surrounding the actual truck vs. rail decision itself. There is no mention in these processes of analyzing the cost associated with protecting against rail shipping variability, damage to goods, required additional rack investment, or even an inventory vs. transportation cost analysis. A group has been established within Ford and is working to outline a more formal decision making process, but these guidelines were not defined during the time of this research. If Ford is to align transportation decisions with corporate strategies the analysts making those decisions will need to be equipped with the proper tools to identify and compare the relevant cost, quality and timing issues of the truck vs. rail decision.

Figure 3-f below identifies the components of the cost of transporting material from one plant to another. When making mode decision (truck vs. rail) each of these costs should be identified, insofar as possible, and compared for the two modes.

Components of Cost:	**Description:**
Transportation Cost	Cost charged by truck or rail shipping company per move including rack return if applicable
Inventory (pipeline, safety, warehouse)	In-transit inventory, plus supplier and customer inventory held to protect against transit variation, plus warehoused inventory
Damage	Damage caused by poor ride quality in transit
Demurrage	Cost charged by truck and rail companies for detaining trailers or box cars over an allotted number of days
Lost production	Cost of production idled due to late arrival of truck or rail car
Premium freight	Cost of deviations in mode due to constraints of transit
Container investment	Cost of rack (related to ride harshness in truck vs. rail) Total number of racks to be purchased (related to pipeline length)
Material handling labor	In-plant labor required to load and unload conveyance
In-plant storage space	Square feet required to store/stage incoming and outgoing material due to conveyance constraints
Material handling equipment	Purchase or lease cost of fork trucks, tugs, AGVs, etc. required to load and unload conveyance
Material management	Number and cost of hours spent managing incoming and outgoing material in truck vs. rail

Figure 3-f Total Cost Components of material movement

Some of these items can easily be quantified, while others are more elusive. Transit cost can easily be identified and quantified for various modes. Inventory cost breaks down into pipeline inventory, which is a function of transit time and variability, safety stock which is held to protect against transit variability, and any inventory being warehoused for other reasons. Simple safety stock calculations available in commercially available packages can determine the in transit inventory and safety stock needed to provide a certain service level given a distribution of transit times. Warehoused inventory costs may relate to "sequencing centers" which assist in the delivery of an ILVS stream of parts into assembly plants, or other types of warehouses based on situational needs.

Damage costs, while very real, are very hard to capture. Data on transit related damage is highly aggregated, and likely underestimates the actual amount of transit related damage. When an assembly plant opens up a box car and finds damaged parts, they must first decide if the damage was caused by poor ride quality or poor supplier material handling. If there is reason to believe the ride quality is at fault, the assembly plant must go through a formal, paperwork intensive process to file a damage claim which the railroad can dispute. If, however, the supplier is thought to be at fault, the supplier is simply charged for defective quality and replacement parts are sent at the supplier's expense. This process seems likely to underestimate the actual level of transit caused damage simply due to the effort required to report it. Nonetheless, damage costs should be factored into the total cost when they are known or can be reasonably estimated.

Demurrage costs accumulate when a trailer or box car is held at a plant for an excessively long period of time due to the plant's actions. In most cases demurrage results when conveyances are used as warehouses. A supplier may over-ship to a customer to alleviate congestion in a supplier plant. The customer plant does not have the floor space to store the excess material, and simply leaves the material in the conveyance until such time as it is required. This can leave trailers and box cars idle for days on end. Truck and rail companies charge for the opportunity cost of this idle equipment, and data on demurrage charges is relatively easy to obtain.

The cost of lost production can be measured as the opportunity cost of idling a plant (supplier or customer) due to the late arrival of a conveyance. As the amount of safety stock is increased the likelihood of lost production decreases. When making transportation planning decisions, the balance between safety stock and lost production must be weighed for both truck and rail. Probabilistic models can determine the expected value of lost production for a given level of safety stock and transit time distributions. The challenge in accurately quantifying this cost component lies in collecting sufficient correct data to accurately characterize transit times.

Deviations to premium freight occur when the normal mode of transit will not get a shipment to a customer by some required time. Deviations can take many forms including faster trains, specially ordered trucks, helicopters, planes, and the occasional employee-with-a-pick-up-truck. Because trains depart from supplier facilities at predetermined "cut off" times, and must meet other trains on a fixed schedule it is unlikely that a railroad will delay a train to wait for one late shipment. In many cases a supplier will only ship once per day in rail. If that supplier is an hour late in getting his goods to the train, he may have to wait for 23 hours until he can ship again. In cases when 23 hours is too long, he must deviate into a different mode of shipment. Unlike rail, a truck can be held for an hour without large systemic consequences. This implies that it is easier to deviate out of rail than out of truck. Because premium freight has significant costs associated with it, the expected value of premium freight should be factored into the cost of a given mode of shipment.

The required level of container (rack and packaging) investment will be different for truck vs. rail for two main reasons. Because rail has a longer and more variable transit time, more racks must be purchased to fill the entire shipping pipeline. This cost is relatively easy to quantify given the racks costs and transit times. What may be harder to quantify is the impact of ride quality on container cost. As discussed above, rail places significantly greater stresses on racks than does truck shipment. Either certain rail racks must be designed to withstand this extra stress, or all racks must be designed to withstand these loads. In either case, the additional durability required of rail racks is not free.

Because rail and truck typically have different shipment sizes, different amounts of in plant storage space may be required. If a plant wants to stage a full conveyance load of material on the dock, a much larger area will be required if the material is being shipped in a box car than if the material is being shipped in a truck. Insofar as square footage is valued differently and is not equally available in all plants, the cost of floor space associated with transportation mode should be assessed.

Finally, the level of required material handling labor, equipment and management may be different for goods shipped by rail than those shipped by truck. These costs can include not only the cost of the hourly personnel who load and unload the conveyances, but the costs of time spent tracking shipments, planning for unexpected variability in shipments, dealing with improperly labeled shipments, preparing conveyances to be loaded or unloaded, leasing or buying equipment to move material and the like. In individual cases the level of these cost for rail and truck will vary. In one plant where the rail docks are very far from the material point of use, additional tugs and tug drivers maybe required to move the material, whereas in a different plant it may be the truck dock that is poorly situated. The impacts of these costs, though very large from the point of view of plant personnel with specific budgets to meet, may be small relative to the total costs of shipping. In any case these costs need to be evaluated and compared for the specific modes of transportation being considered.

Evaluating the above listed costs for every move of every part destined for a Ford assembly plant could quickly consume the resources of an unjustifiably large number of analysts. What would be more sensible would be to evaluate these costs for a small sample of parts and moves to determine the relative weights of the various cost components. With an understanding of these costs Ford can establish which ones will figure into every analysis and which ones will only be calculated in certain circumstances. This effort need not begin at ground zero. In evaluating the cost savings of outsourcing the logistics function at the Oakville assembly plant, Ford hired Bain & Co. consultants to estimate many of the above parameters. Simply determining the costs associated with a small number of moves may shed some light on the relative weights of the cost components, but a more complete understanding must include a characterization of how the

specifics of a move (i.e. large racks vs. small, heavy components vs. light, high value per cubic foot vs. high value per pound, etc.) affect the contributions of each cost component.

3.3.3 A Competitor's Decision Making Process

It is interesting to examine the truck vs. rail decision making process of a competitor for the purposes of comparison. Because this competitor has significantly less geographic dispersion in both suppliers and assembly plants, there is much less rail shipping relative to Ford. Half of this competitor's assembly plants do not even have rail sidings. In terms of the number of moves by rail, the competitor's system is much smaller and easier to manage. The competitor does, however, make greater use of cross docking[31] and near-site warehouses, which complicates the decision making process.

When making a truck vs. rail decision, The competitor's rail expert says he begins with a historical knowledge of what parts might be candidates for rail based on volumes, weights, etc. (This is very similar to what Ford's analysts said.) He then asks the following questions:

- Do the supplier and assembly plant have rail dock facilities?
    - 8 of the competitor's 16 assembly plants are not rail equipped.
    - Many facilities are served by rail warehouses- material goes in box cars to warehouses which unload, sequence, and repackage material into trucks. (These "Flow through" warehouses are operated by outside companies)
- Do the daily volumes and geography justify it?
    - What are your daily volumes (measured in rail car loads vs. truck loads)
    - What is the geography of the move (measured in miles)
    - Weight concerns and box car length concerns (will you exceed the weight capacity of a truck before you fill it?)
    - Given part volumes, geography, and packaging, what are your inventory costs?

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[31] Cross docking refers to the transfer of material from truck to rail.

- Does the packaging accommodate it?
    - Can racks go in rail? (Are they sturdy enough and the correct dimensions?)
    - Note: The competitor, who does very little rail shipping, has designed racks to be 108 x 50 to fit in trucks (102 wide, 2 across) or rail (110 wide, 1 across). They are trying to standardize these rack dimensions.

Once the above questions are answered a single page unit cost comparison is prepared.

Sample Competitor Transportation Study Matrix
Engine Transportation from Engine Plant to Detroit Assembly Plant

Alternative 1: Box car from engine plant to Detroit warehouse. Ship to assembly plant as needed
Alternative 2: Box car from engine plant to Detroit cross docking facility, immediate transfer to tucks for delivery
Alternative 3: Direct truck from engine plant to Detroit warehouse, truck to assembly plant as needed
Alternative 4: Direct truck from engine plant to assembly plant- store at assembly plant until needed
Alternative 5: Air freight from engine plant to assembly plant- store at assembly plant until needed
Alternative 6: Build rail dock at assembly plant for direct receipt of engines by rail (requires $500,000 investment)

Alternative	Total Loads per year	Round Trip Transportation Cost	Annual Transportation Cost	Transit time (days)	Inventory Carrying cost- 14%	Total Transit cost	Warehouse cost per 6 mos.	Warehouse-Assy Plant trucking	Total Cost	**Cost per unit**
1. Rail/Whse	50	$ 6,500	$ 325,000	15	$ 73,500	$ 398,500	$ 100,000	$35,000	$533,500	**$ 26.68**
2. Rail/x-dock	50	$ 6,500	$ 325,000	15	$ 73,500	$ 398,500	$ 35,000	$35,000	$468,500	**$ 23.43**
3. Truck/Whse	175	$ 4,000	$ 700,000	3	$ 14,700	$ 714,700	$ 100,000	$35,000	$849,700	**$ 42.49**
4. Truck Direct	175	$ 4,000	$ 700,000	3	$ 14,700	$ 714,700	$ -	$ -	$714,700	**$ 35.74**
5. Air	N/A $250/engine		$ 5,000,000	2	$ 9,800	$ 5,009,800	$ -	$ -	$5,009,800	**$ 250.49**

Assumptions:
Annual volume: 20,000 engines /year
Daily demand: 70 engines/day
Cost of engine: $500 per engine
Warehouse cost includes: rental of climate controlled warehouse with inventory control, handling charges,and paperwork charges

Figure 3-g A Competitor's Transit Mode Decision Matrix

At the beginning of this chapter we posed three questions: How are Ford's strategic initiatives changing the demands on rail service, how do the railroads view their auto parts business, and how is Ford's truck vs. rail decision making process equipped to deal with the changes in Ford's needs and the railroads changing services? The answer to the first question is that there are a variety of impacts of Ford's new strategies. Generally speaking Ford's new way of doing business will require greater discipline from the railroads just as it requires greater discipline from Ford plants and departments. The railroads seem to want to meet Ford's needs, but there are

infrastructural and potentially cultural barriers to changing service to the extent required. It seems that Ford's decision making process has not yet evolved to account for the new requirements, but that relatively simple analyses (like those performed at a competitor) can shed much light on the trade-offs being considered.

4. Customer Needs Analysis

The conventional wisdom surrounding rail transport clearly suggested that the fit between rail and Ford's new vision for manufacturing was poor. What the conventional wisdom does not tell us is how we should improve that fit. To determine what changes to equipment design and logistics management would increase the appeal of rail, we need to step down the ladder of abstraction to uncover the needs underlying the conventional wisdom. For this we choose to borrow an approach from product development- the structured customer needs analysis. The hope is that by eliciting and documenting the specific, unfulfilled needs which give rise to the common perception of rail as an unattractive mode of shipping we can create design specifications to guide alterations to rail equipment and logistics. In this chapter we will examine the process used for eliciting and understanding these needs.

The first step in a customer needs analysis is to identify the customers. For the purposes of this analysis, the "customers" of rail were broadly defined to include all Ford functions with concern or responsibility for some aspect of rail shipping, as well as rail shippers and rail equipment manufacturers. In a typical product development customer needs analysis, there is usually little doubt as to who the customers are, and there is not often a conflict between the needs of different customer groups if the product mission is properly defined. Where conflict does arise in traditional product development customer groups, it is possible to choose to focus on the needs of one group over another without significant adverse effects. This is usually referred to as narrowing the target market, or finding a market niche. As we will see, when applying a customer needs analysis within a large corporation we encounter conflicting customer needs that must be resolved. Thus the definition of our customers is an important and difficult step.

The customers whose needs will be considered in this analysis are the following:

- **Assembly plants** - Ford North American assembly plants
- **Supplier plants** - Both Ford plants and supplier plants, with an emphasis on Ford plants
- **Material Handling and Packaging Engineering** - The Ford organization responsible for rack design, in-plant material movement systems, and material handling equipment.

- **Material Planning and Logistics** - The Ford organization responsible for the design and management, of inter-plant material transportation. Also responsible for material tracking and planning information systems.
- **Transportation Procurement and Customs** - The Ford organization responsible for negotiating and procuring service from transportation providers. Only the rail procurement group was involved in this analysis.
- **Ford Production System** - The Ford organization responsible for guiding the implementation of the Ford Production System principles in Ford plants and throughout the Ford supply chain.
- **Rail Shipping Companies** - In this analysis, Norfolk Southern provided the rail company voice. NS is Ford's largest rail shipper.
- **Rail Equipment Manufacturers** - In this analysis the TTX company provided the voice of a rail equipment supplier.

Each customer was interviewed in the environment in which he interacted with rail. In some cases this meant interviewing customers while riding a locomotive, and in other cases it implied an interview in an office with a computer and a phone. For the most part all customers were asked similar questions regarding their interactions with rail. For example, issues of rail reliability were discussed with all rail users. In some cases certain aspects of rail were transparent to one or more users. (e.g. The Material Planning and Logistics organization was not significantly aware of or concerned with the ease of operating box car doors.)

Once all interviews were completed, customer statements were translated into system features. For example if a customer said, "I really wish the doors were not so hard to open. It's a real problem when a door sticks and I can't get at the racks inside" we might translate that statement to read, "Access to the interior of the car must be easy and reliable" Once all customer statements were translated, the list of system features was condensed from over 200 features to 52 features which represented the essence of what the customers had described.

The condensed system features list formed the basis for a survey. This survey asked the customers who had described their needs to assign an importance to each of the system features. The intent of this survey was to generate a prioritized list of desired system features which would be used to guide the design and alteration of rail logistics and equipment. An unexpected result of this survey was to illustrate the disparity between strategic corporate initiatives and the self described wants of both the plant and staff personnel.

4.1 The voice of the plant customers

Interviews with plant personnel were conducted in seven production plants and one parts distribution center. The seven plants were chosen to represent a cross section of Ford's manufacturing plants as well as a variety of technological capabilities. Table 4-1 below shows the seven plants, the functions interviewed at each, and the level of success the plant has had in implementing technologically advanced material handling.

Location	**Functions of interviewees**	**Observed technological success of plant material handling**
Milan Plastics	Material control	High
Utica Plastics	Material control, fork lift driver	Low
Buffalo Stamping	Material handling engineering, shipping, fork lift drivers, material control,	High
Woodhaven Stamping	Staff material handling	Medium
Twin Cities Assembly	Material handling engineering, material control, receiving, computer integrated manufacturing	High
Windsor Engine	Shipping, staff material handling	Medium
Lorain Assembly	Material control, material handling engineering, receiving, fork lift driver	Low

Table 4-1 Plant Customers

There were several complaints that were common to all plant customers. The most prevalent complaint was of door malfunction. Opening the doors on a box car requires a person to reach over the gap between the rail car and the dock to twist a locking mechanism which allows the

door to open. The person must then slide the door sideways to gain access to the interior of the car. If any of the rails on which the door rides are bent, improperly adjusted, or insufficiently lubricated the effort required to open the door can exceed the capabilities of even a very strong person. When this occurs, the person attempting to open the door will often use the forks of a powered fork lift truck to force the door open. This action often involves impacting the door at an angle to its direction of intended travel. This impact can further damage the door hardware, making it even harder to open.

Doors can be damaged not only by improper opening, but by impact from within the car. When a rail car is being loaded or unloaded, it is often the case that only the doors on one side of a car are opened. When this is the case a fork lift driver loading or unloading racks from the car is likely to hit the closed doors from the inside of the car. According to railroad personnel, both doors are supposed to be opened during any loading or unloading to prevent this type of damage. One can observe the indentations made by lift truck forks on both the inside and the outside of the box car doors.

Although door maintenance is the largest complaint from plant personnel, other maintenance issues were cited including holes in the roof and floors, bent rails along the interior walls of the rail car, broken or splintered floors, and nonfunctioning cushioning devices. Occurrences of broken doors or other maintenance items are so prevalent that most plants have personnel from the railroads on site to deal with such problems as they arise. One plant claimed to call on these maintenance personnel at least once per shift to fix a broken door.

Other common plant complaints about rail included the condition in which racks were returned from assembly plants, the inaccuracy of information regarding box car contents, and the unreliability of rail delivery. There were instances in which certain characteristics of rail were of great concern to one plant, but seemed not to be an issue at another. For example, personnel at the Lorain assembly plant did not view the delivery reliability of rail as a problem, whereas this was cited as a primary concern at the Twin Cities assembly plant.

Among the attractive aspects of rail cited by many plant personnel were the large shipment size relative to truck, and the physical location of rail docks within the plant in some cases. From a receiving perspective, spotting a rail car into a plant requires much less effort than bringing in the three to five trucks that would be required to carry an equivalent amount of material. Most plant personnel actively did not want to see a move to smaller loads in rail cars. Some plants have optimized portions of their plant layout for material flow to and from rail cars.

4.2 The voice of the staff customer

Of the customers listed above, several fall into a category termed "staff" customers. This group of customers interacts indirectly with rail as a shipping mode as described above. One would expect these customers to have very different needs than the plant customers who come into physical contact with rail cars every day. Given the various ways in which these customers interact with rail, we would expect a low degree of commonality in the customer needs statements. Despite these diverse perspectives, a few common themes emerged.

Most staff customers were concerned in one way or another with the transit time rail provides. Material Handling viewed this as a concern due to the increased rack purchase requirements; Material Planning and Logistics expressed concern over the inventory costs associated with a long pipeline; the Ford Production System representative believed that many rail transits would exceed the allowable transit time; Transportation Procurement worried that the longer transit time would increase the number of rail cars required, which would in turn increase the price of rail service.

Most staff customers also expressed concern over delivery reliability. To FPS, this issue is critical since unreliable delivery will shut down plants in a lean supply chain. To some of the other organizations, delivery reliability was only an issue insofar as it generated complaints from the plants, which filtered up through the various organizations.

One surprising result was the lack of concern over rail's perceived inability to provide cost effective shipment for small batches on a frequent basis. Only FPS expressed any concern over this issue at all. We will examine this in more detail when we examine customer survey responses.

Some staff customers seemed most frustrated with the relationship with the railroads, rather than with any one specific aspect of rail shipment. Words like "old school", "inflexible" and "unresponsive" often surfaced in discussions of the railroads. The first slide of a presentation given by Material Handling to the railroad companies on the role of rail in Ford's future contained the following:

> "Webster's Definition of Railroad: To push through hastily or without due consideration. Webster considers this the definition of a verb, we consider it the definition of a noun."

4.3 The voice of the Non-Ford Customers

Because rail shipping involves not only Ford manufacturing facilities, but railroad companies and rail equipment manufacturers as well, representatives from these groups were interviewed as "customers". The top concern of Norfolk Southern seemed to be equipment utilization. Because the railroads have a large depreciation expense, idle equipment represents a significant cost. Along with the opportunity cost of idle box cars, railroad executives cited the logistics costs of rerouting cars in non-standard paths as a concern. These non-standard moves typically arose when parts that were normally shipped by rail were deviated to truck, and Ford wanted the rail companies to ship the empty racks back via rail.

Norfolk Southern also expressed concern over variability within the rail system. They cited adherence to cut off times (i.e. how often plants are ready to release a rail car at the scheduled release time) as a cause of schedule variability. Better blocking was cited as a way that Ford policies could contribute to the efficiency or inefficiency of rail switching, and as an area in which the railroads would like to see improvement.

The nature of the rail logistics system seems to put the railroads in a rather difficult position. On one hand, the rail system only provides reliable delivery when all participants in the system meet the predetermined schedules. For example, delaying a train for a few minutes to allow a customer's shipment to not have to wait for the next day's train has adverse impacts on the timely

delivery of other customer's shipments. On the other hand, the rail companies would like to be as flexible as possible to their customers' needs. This may mean allowing customers to be a few minutes late in getting all of their goods ready to ship. The interdependencies of the rail system make it not well suited to be highly flexible to customer needs while providing reliable, low cost service.

Rail companies have dealt with the conflict between customer focus and system efficiencies in two notable ways. Most major rail companies offer not only pure rail service, but intermodal service in a variety of forms. Many rail companies are also trying to be full service logistics suppliers. Both of these moves help decouple the customers from the sensitive scheduling of rail. As a full service logistics supplier, a rail company has control over deviation mode decisions. If the cost to the rail company of sending a shipment via truck is less than the cost of delaying a train to wait for that shipment, the rail company is free to make that choice. If a supplier's goods were not ready for shipment in time for the scheduled train departure, the rail logistics supplier could truck the goods to a downstream rail stop, thus leapfrogging the train, and load the parts on the train for the rest of their journey.

4.4 Needs prioritization

Once interviews with all relevant customers were completed, customer statements were translated into system features. These features were condensed into a list of 53 summary features, which the customers who had been interviewed were asked to rank. Customers classified each feature as being either Critical, Desirable, Neural, Undesirable, or Unacceptable. Table 4-2 below shows the systems features included in the survey. The order in which the features are listed reflects the survey results. The number next to each feature reflects the order in which the feature appeared in the original survey.

4.4.1 Survey results

Returned surveys were consolidated by location to prevent a single plant or group with a high number of respondents from biasing the results. Rank ordering the results of a survey such as this

can be accomplished in a number of ways, none of which seems ideal. One can "average" the responses and order them by this average, but it is incorrect to think that two responses of "neutral" equate to one response of "critical" and one response of "unacceptable". This ordering scheme works best where the categories do not contain opposites such as critical and unacceptable. If the scale on which a feature is being rated goes from "pretty good" to "truly outstanding" averaging may be appropriate.

Figure 4-a below shows the responses to the survey represented graphically by the percentage rankings for each category. The responses are ordered by the "average" response[32], and it is clear that this ordering leave something to be desired. What the graphical method allows is for an easier way to examine the results for each question on the survey, and to compare responses to one another visually. From this representation of this data we can see that there is a clear upper echelon of self described customer needs.

	System Feature
33	If there is some automation in the system The system can be operated manually in the event of a system malfunction.
48	The system minimizes safety risks.
46	The system reliably delivers loads on time.
2	The system provides accurate information to the shipping/receiving docks regarding car contents.
37	The system minimizes the possibilities for handling damage.
17	The system provides a smooth and consistent flow of material and racks between the rail car and production.
35	The system delivers racks and parts in the exact condition in which they were shipped. (Racks and parts remain undamaged)
4	The system provides error checking for car contents. (It prevents you from having different parts on the ASN than are in the car.)
1	The system imposes the same constraints on rack return as it does on inbound parts. (The dunnage bars are fastened, the racks come back in a timely manner, etc.)
3	The system is easily managed (allocating manpower is a simple task).
34	The system should have a long useable life.
24	The systems allows racks to be loaded and unloaded in stacks of 2 or 3 high.
38	The system reduces the amount and force of load shifting during transit.
32	Replacement parts for the system can be obtained in a timely manner

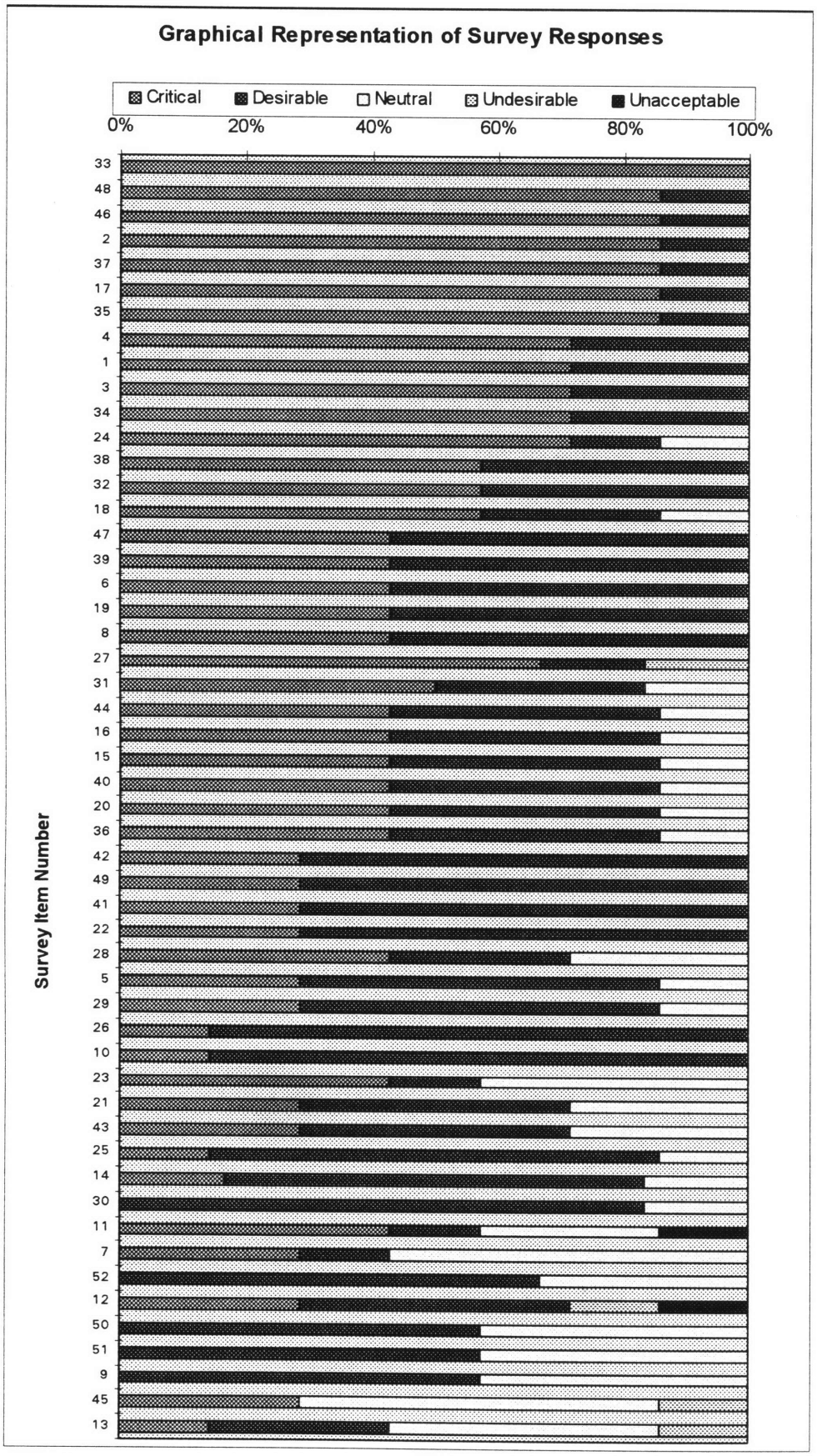
[32] Critical = 5, Desirable = 4, Neutral = 3, Undesirable = 2 and Unacceptable = 1. So a question to which half of the respondents replied "critical" and half said "unacceptable" would have an average of 3, equivalent to "neutral".

18	The system reduces congestion on the docks.
47	The total system transit is minimized
39	The system minimizes the voids within the car.
6	The system is flexible enough to accommodate unforeseen production changes and loading patterns.
19	The system allows cars to be loaded and unloaded in the shortest possible time.
8	The system has a single type of load restraint that is usable for all types of loads.
27	The system should provide excess transportation capacity to cover volume fluctuations.
31	The system does not increase skilled trades headcount.
44	The system reduces the total cost of inbound rail shipment.
16	The system reduces the number of people required to handle rail loads.
15	The system reduced the number of man-hours required to handle rail loads. (But not necessarily the total headcount)
40	The system prevents dunnage loss/detachment.
20	The system eliminates double handling of racks/parts
36	The system provides accurate information to the shipping/receiving docks regarding interior car dimensions.
42	The system provides accurate information to the shipping/receiving docks regarding required maintenance.
49	The system is well received by plant floor personnel.
41	The system reduces the cost of deviated shipments.
22	The system minimizes the distance that parts and racks need to be carried.
28	Training on the system is available to a large number of people at a low cost.
5	The economics of the system can be easily analyzed and understood.
29	The system can be maintained by plant skilled trades.
26	The system allows cars to be serviced (preventative maintenance) while still in operation.
10	The system provides accurate information to the shipping/receiving docks regarding location of parts within the car.
23	The system only presents racks/parts that will be used within 1 day (parts are not conveyed to storage)
21	The system allows access to any rack in the car at any time during the unloading process. (e.g. full side access)
43	The system allows for cheaper, lighter racks to be used.
25	The system prevents improper cubing. (It is only possible to load racks in the optimal cubing arrangement.)
14	The pick up and drop off locations for parts being loaded/unloaded can easily be changed.
30	The system requires equipment vendors perform service.
11	The system functions equally well for cars at various different ride heights
7	The system delivers small batches on a frequent basis.
52	The system allows palletized goods to be stacked within the car.
12	The system allows more than one commodity to be shipped in a car.
50	The system automatically removes racks from the car, and places them in a staging area.
51	The system automatically removes racks from the car, and delivers them to the linefeed location.

9	The system automatically provides access to the inside of the car (without having to lay a dock plate)
45	The system ships no more than one day's worth of parts at a time.
13	The system allows for the shipment of partial loads.

Table 4-2 Customer Needs Survey System Features

Figure 4-a Graphical representation of survey responses (Facing Page)


Graphical Representation of Survey Responses
Critical
Desirable
Neutral
Undesirable
Unacceptable
0%
20%
40%
60%
80%
100%
Survey Item Number
33
48
46
2
37
17
35
4
1
3
34
24
38
32
18
47
39
6
19
8
27
31
44
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45
13

4.4.2 Strategic Objectives vs. Stated Customer Needs

The results from the customer needs survey seemed to indicate a conflict between the higher level strategic goals of the organization and the stated customer priorities. For instance, FPS requires small batches and frequent deliveries yet this feature ranked very low on customers' lists of needs. Interestingly, automation ranked at the bottom of the list of customer wants. The low ranking features from the customer needs survey seemed to all represent a departure from the traditional way of doing things. Small batches and automated box cars are not part of the current rail paradigm. One can explain this commonality in two ways. One possibility is that rail users define as critical those things which are consistent problems today, and that new features rank low because users are already getting along without them. A customer might think, "How critical can a feature be if I'm getting along without it today?" Twenty years ago a customer needs survey might have shown that using computers to track box cars was not a desired feature, yet today it is considered essential.

A second possible explanation for the low ranking items is that they really would not be of use to the customers, now or in the future. In the 1980s General Motors saw automation as the key to future success, but history has not substantiated this view. There were doubtless many GM plant veterans thinking, "I knew that was a bad idea" as they watched the expensive robotics being hauled out of the plants. This may be the case with rail car automation, or small batches in big box cars.

What this customer needs survey highlighted was a potential misalignment of strategic goals and stated day to day operating needs. Surprisingly, it was not only the plant customers who were opposed to small batches and automation, but high level managers as well. This potential misalignment indicated a need to prioritize project objectives. Attempts to involve the members

of a Material Handling Technology Forum[33] in the process of prioritizing these needs met with little success. The general feeling among forum members was that prioritizing these needs without any design concepts to look at was not a worthwhile task.

Based on the wants of the forum members, study of rail transport was divided into two areas- equipment and logistics. In the next two chapters we will examine issues of logistics and equipment in more detail. Although it is clear that these issues are not entirely independent, it is useful to discuss them separately, and to identify the areas where one impacts the other.

[33] The Material Handling Forum is comprised of the heads of material handling in Ford's various organizations as well as technology development personnel from Ford's Advanced Manufacturing Technology Development Center.

5. Logistics Issues

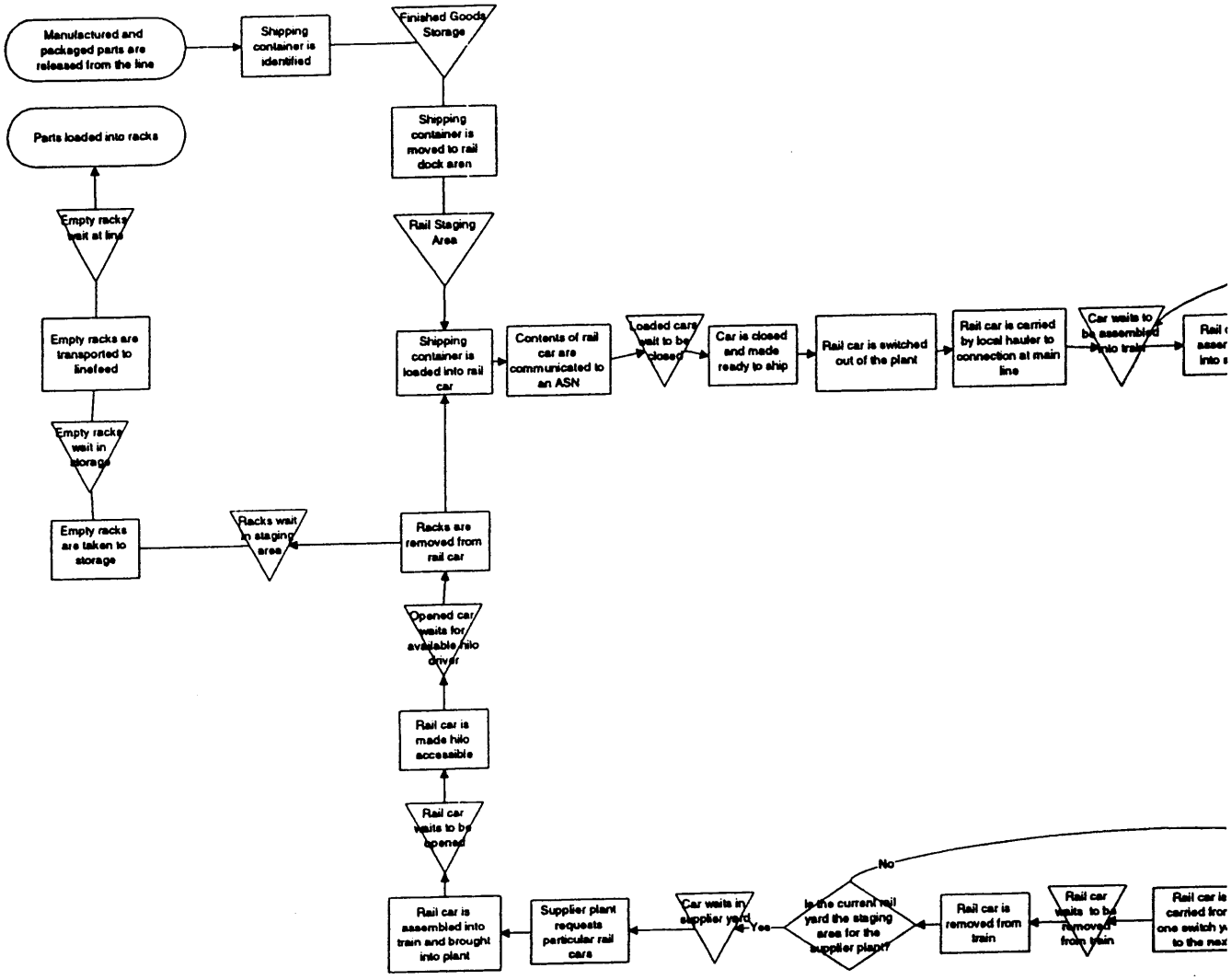
In this chapter we will examine the logistics of transporting material between supplier and assembly plant by rail. We will begin by examining the detailed process by which individual racks of material are move through plants, and how box cars are moved from origin to destination. We will then take a higher level look at the box car movement process and characterize this process in the time domain to learn where box cars are spending most of their time. We will also discuss how in-plant material flow affects the logistics of box car movement. Finally, We will examine a pricing model which attempts to predict the cost of a move to Ford based on the parameters describing that move.

5.1 Process Flows

Rail shipment can be broken down into two separate processes: movement of the rail cars, and movement of the full and empty racks. The process for moving rail cars includes navigating the rail network from supplier to customer plants, the movement of cars into and out of repair yards, the transfer of cars from one origin pool to another, and the delays cars experience sitting in various yards. The process for moving full and empty racks includes the time the racks are in moving or delayed box cars, as well as the flow of materials and racks within the supplier and customer plants. For the purposes of this study we will focus on those steps in the rail car movement process which convey full and empty racks between customers and suppliers. Although we will discuss the implications of moves to repair yards, and transfers between origin pools, we will not map these processes in detail.

Figure 5-a illustrates a detailed process flow for both rail cars and racks (full and empty). The key feature of this process flow is the number of "buffers" or steps that require a rail car and its contents to wait. Note that there is a repeated step in which the rail car is moved from one yard to the next. In extreme cases this step can happen more than ten times in a given route. Note also that while this process appears to be relatively straightforward, there are several points of convergence and divergence where multiple process flows converge. For example, when a box car is in a yard waiting for a connecting train to arrive, several trains with their various cargoes must arrive before the process of blocking the rail cars can begin.

Detailed Rail Shipping Processes



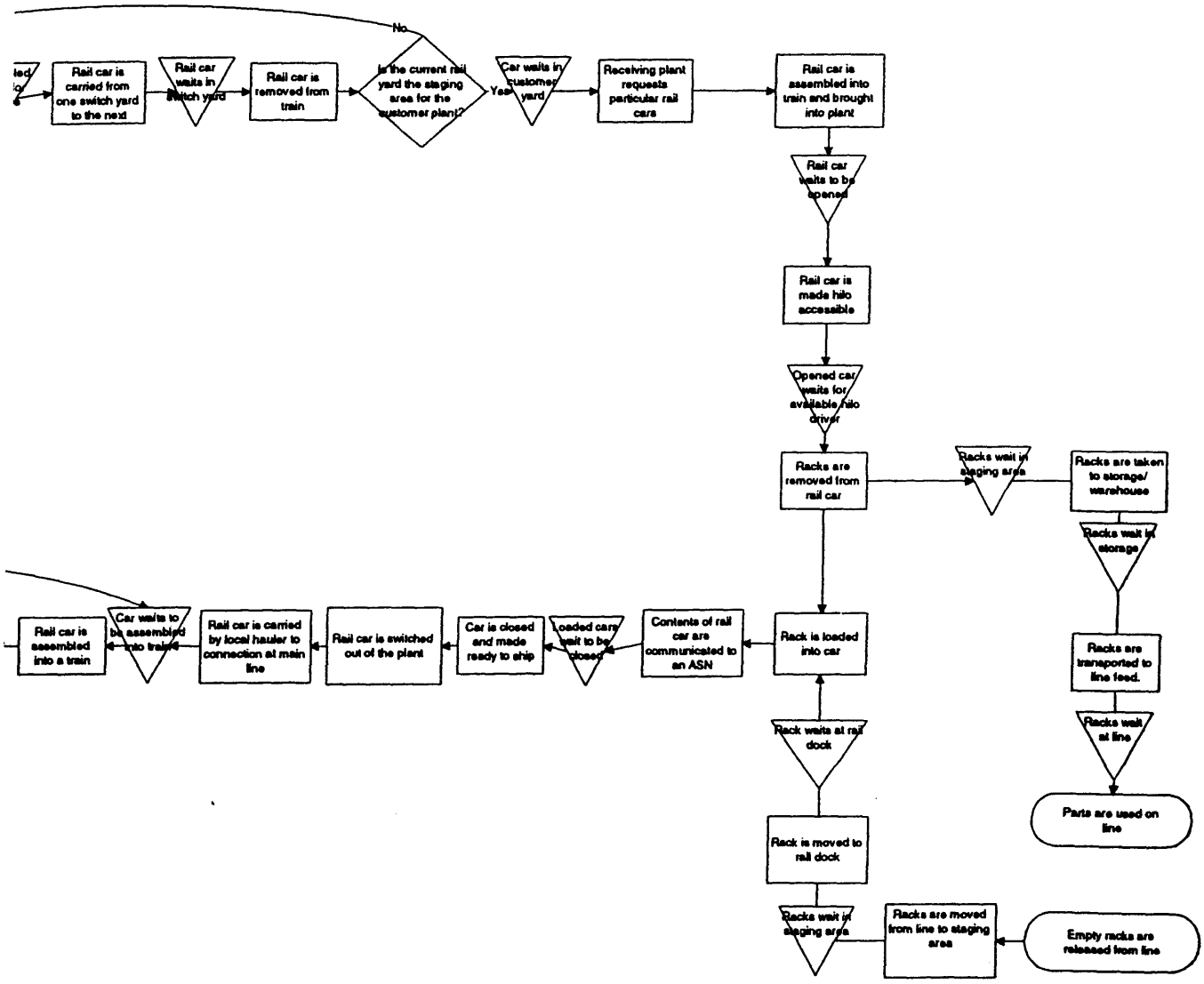


Figure 5-a Rail Shipping Process Flow

5.1.1 Box Car Movement Processes

As can be seen in Figure 5-a above, the process of moving rail cars is a simple one. A car begins as a part of a series of cars located in a plant- the origin plant. These cars are then pulled by a locomotive into a nearby rail yard at a predetermined time. The cars are then sorted by destination. (i.e. all of the cars going to Atlanta are grouped together, and separated from the cars going to other destinations.) Each group of cars then waits for a connecting train to arrive. The cars are then coupled to the connecting train and pulled to the next yard in their route. The cars are then sorted by destination, and the process repeats. This repeats until the car is delivered into the destination plant.

The detailed box car process flow shown above can be grouped into six major process steps[34]:

- **Supplier Loading**: The period when a supplier has a rail car spotted at his rail dock, and can be loading parts into the rail car or removing empty racks from the car. Note that a car may be in the "supplier loading" stage for several hours, even if the actual loading and unloading of the car takes only an hour.
- **Moving Loaded**: Once the car is removed from the supplier's plant by a railroad it enters the "moving loaded" phase. During this part of the process, the rail car contains racks loaded with parts destined for a supplier and is being moved along a route from supplier to customer. Not all of the time in this step of the process is spent actually moving. Much of the time is spent waiting in switching yards for connecting trains.
- **Delivered Loaded**: When the car is delivered to the customer's rail yard and is available for use by the customer, it is considered "delivered loaded". A car may wait in this stage for several days until the customer requests a particular car be pulled into the plant. This stage represents a buffer at the customer location.
- **Customer Unloading**: Once a rail car is spotted into the customer's plant it remains there for a fixed length of time during which the customer may unload the full racks and reload empty

[34] The terminology for these steps comes from the rail car status designations in the TRRIPS system, which tracks rail cars along their routes.

racks into the car. As with "supplier loading", the actual time required to unload and load a rail car may be much less than the amount of time the car spends in the plant available to be loaded and unloaded.

- **Moving Empty**: This step is simply the return of empty racks from customer to supplier and has the same characteristics as the moving loaded phase, although the duration of this step is typically longer than that of "moving loaded".
- **Delivered Empty**: This is the comparable step to delivered loaded for the return of racks. Cars with empty racks will sit in a supplier's yard until the supplier plant requests that a given car be spotted into the plant, and the cycle begins again.

It is important to note that within each of these larger aggregated process steps there are several delays which represent wasted time. Nonetheless, we can gain some insight by examining the relative lengths of the aggregated process steps. Figure 5-b below shows the distribution of rail cars within these six steps for the stamping and engine rail car fleets. Because the size of each of these fleets does not change on a daily or weekly basis, the percentage of cars in each step is the same as the percentage of the total round trip time that a given car spends in each step.[35]

[35] Ergodicity tells us that the percentage of time spent in a given step is the same as the percentage of box cars in that step, assuming a closed system.

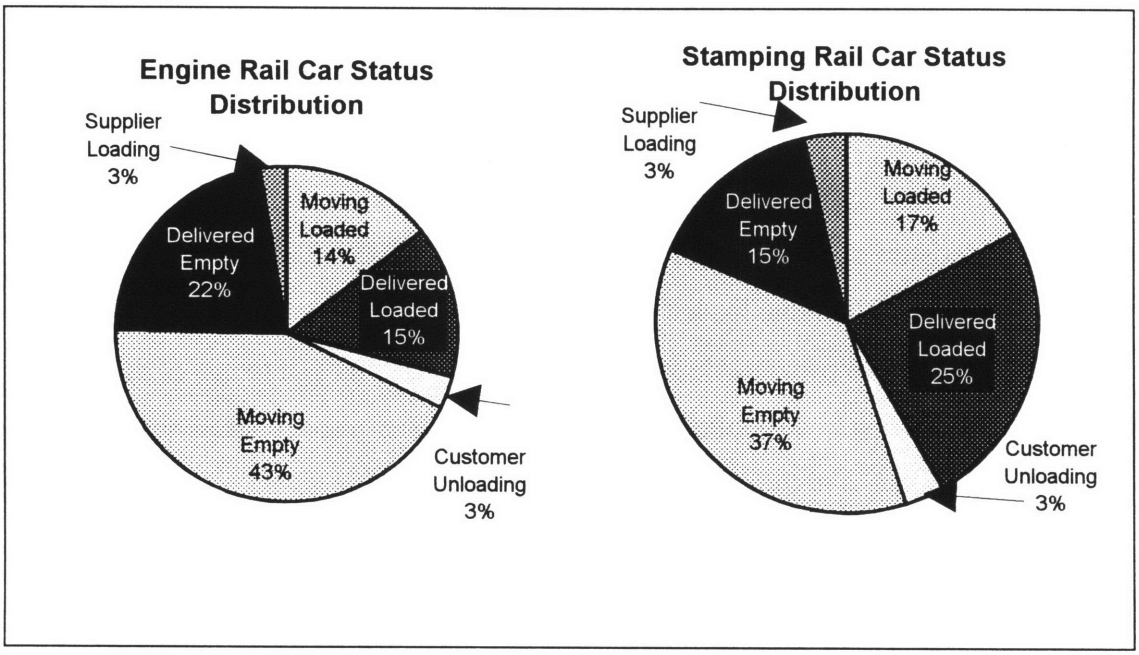


Figure 5-b Status Distribution by % of Fleet

5.1.2 In Plant Material and Rack Processes

Within Ford there is no one standard process for conveying goods and racks between production and the rail docks. The process flow in Figure 5-a above shows the most generic description of what happens when racks are removed from a rail car, and how racks get loaded back into the rail car. In reality, each plant manages these processes differently depending on the local management focus, layout, and production schedules. At a high level we can categorize these processes into two types: closely coupled and movement decoupled. The difference lies in the amount of material sorting and buffering between the rail car and the production point of use.

Closely coupled rail flow:

In a plant where the rail cars and production are closely coupled, racks are taken from the rail car, and placed directly into a line feed area or machine. Typically this process is done by one operator with a fork truck. Material is not placed into any buffer other than the line side material storage. In assembly plants with closely coupled material flow, the full racks of a given commodity are removed from the rail car, and the empty racks for the same commodity are reloaded into the

same car. Because a fork truck can only carry one or two racks at a time, the movement distances must be small for a closely coupled flow to be efficient. This requires that the rail car be spotted as close as possible to the line feed location or point of use.

Notice that in a closely coupled system, the type of rack in the box car is always the same. In the example shown in Figure 5-c, fascia racks never go into the car that delivered stampings and vice versa. This implies that a given car will return to the location from which it was shipped. Suppose that both a plant supplying engines and an assembly plant receiving those engines had tightly coupled systems. In such case a given rail car would become "captive" to the route between the engine plant and the assembly plant. Plant personnel may be blind to the fact that the same car is carrying the same goods back and forth since this state arises naturally and requires no management effort.

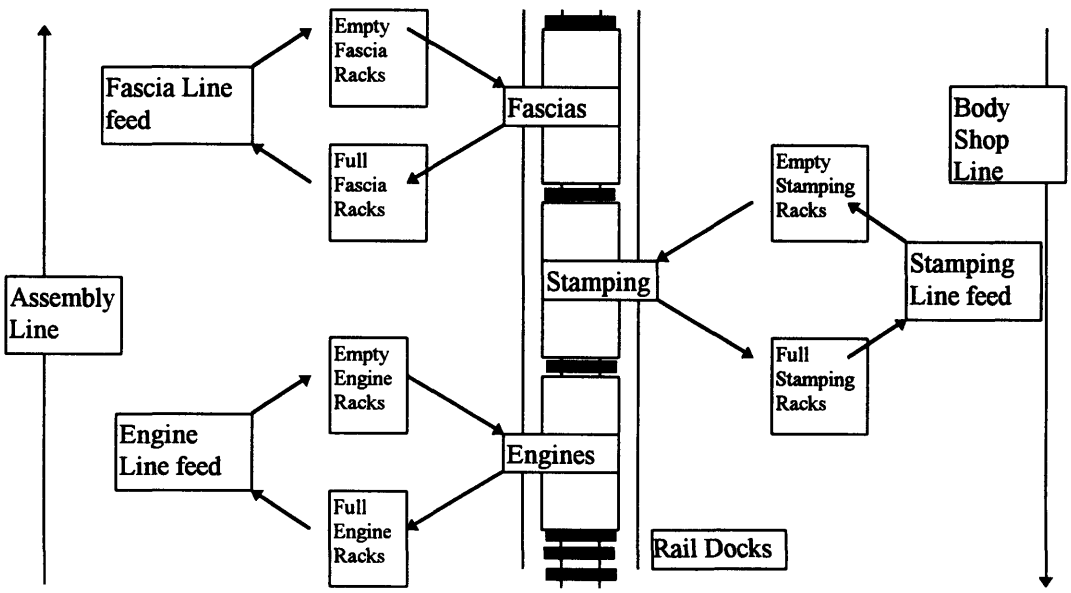


Figure 5-c- Tightly Coupled Material Flow in the Lorain Assembly Plant

Movement Decoupled Material Flow:

In the closely coupled system described above, the movement distances are small, and there is no buffering between the rail cars and the line feed locations. In systems which are what we will call "movement decoupled" the distances over which material is moved are typically large, and there are often buffers or staging areas for material between the rail car and the line feed location. In these systems a rail car will be emptied entirely into a storage location. The storage location will

depend on the particular commodity and the availability of floor space at the time of unloading. It is not unusual to have a fork truck driver unload material from the rail car onto a series of tow dollies which transport the material over a long distance to the point of use or to a storage location.

Because a movement decoupled system includes in process buffers and separates the rail cars from the point of material use, it is not unusual to see one commodity (or type of rack) get unloaded from a rail car and a different type of rack (or commodity) get loaded back into the car. For example, the Buffalo Stamping plant might unload empty door panel racks returning from the St. Thomas assembly plant from a rail car, and load full body side racks destined for Oakville back in the same rail car. This implies that any given rail car is not likely to remain "captive" to a given route without significant management intervention.

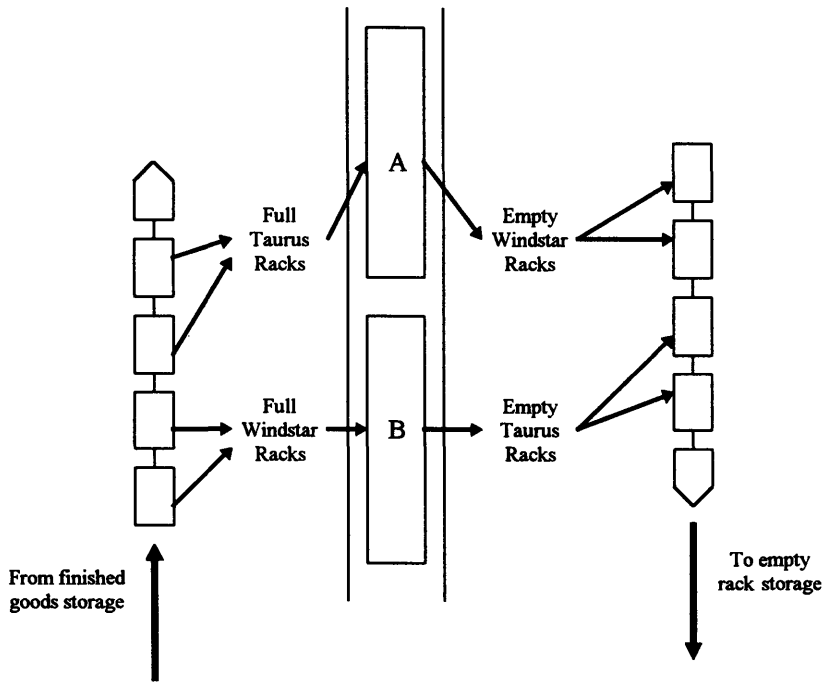


Figure 5-d Movement Decoupled Material Flow in the Buffalo Stamping Plant

Notice that in Figure 5-d, rail car "A" was brought into the stamping plant containing empty Windstar racks from the Oakville assembly plant. It is being loaded will Taurus full racks destined

for the Atlanta assembly plant. Rail car "B" is being unloaded and reloaded in the reverse pattern. These rail cars will not naturally become captive to a given route, but rather they tend to move to various destinations. For this to occur without any major management intervention, there can not be features which make one car suitable for only one type of rack or commodity. (i.e. both cars A and B must be able to carry Windstar or Taurus racks.)

The distinction between closely coupled and movement decoupled material flow has two implications when considering modifications to the rail system and to box cars. First, we notice that certain commodities traveling on certain routes generate naturally captive box cars. If we suggest a modification that would make a box car unique in some way, we would look to implement this modification on naturally captive cars. To implement it on cars that were interchangeable would introduce scheduling and equipment capacity constraints into a system that already lacks sufficient capacity[36]. Secondly, the material handling challenges of unloading to a unique line feed mechanism are likely to be more significant than those of unloading to a standardized material handling conveyance (like a string of tow dollies pulled by an automated guided vehicle.)

5.2 Costing Model

5.2.1 Regressions

Rail pricing is done primarily by negotiating the price on a route by route basis. According to one rail company, the price of a given route is determined by two major components: the train/engine cost and the car cost. The train and engine cost includes the cost of crews, fuel, maintenance of both locomotives and the track system, corporate overhead, and the logistics cost for managing unique or dedicated cars. The car cost includes the cost of car depreciation and maintenance, any new car purchase costs, and required engineering costs. It is interesting to note that the railroads claim to price based on availability. If there is an excess of 60 foot box cars, and a shortage of 86 foot cars then the cost of a move in an 86 foot car will include the cost to fabricate a new car. This implies that the cost of rail transportation to Ford is dependent on what other rail shippers

[36] We will discuss the issue of fleet capacity at the end of this chapter.

are doing. Given the current shortage of 86 foot cars, this implies that moves in 60 foot cars should be cheaper on a normalized basis. The rail company also stated that volume discounts are offered for routes with a higher number of box cars per day.

What follows is an analysis of the prices that Ford is currently paying for all of its North American rail routes, excluding certain destinations in Mexico.[37] We begin with the hypothesis that the cost of rail transport between an origin and a destination is a function of four variables:

- Distance between origin and destination as measured in miles
- Duration of the move as measured in days
- Weight of the shipment in hundreds of pounds
- Volume of traffic moving along the given route (in box cars per day)

Regression analysis of route pricing based on these variables for both 86 foot and 60 foot cars yields only two of significance- the length and duration of the route. This runs counter to the railroad's assertion that weight and volume play a role in pricing decisions.[38] Regressions on the two significant variables yield the following results[39]:

Equation 5-a For 86 foot cars:

Cost per box car on a given route =	\$800 +	\$1.50/mile +	\$75/day
(t-stats)	(9.08)	(13.52)	(3.60)
(R^2=0.644)			

[37] In many cases, Ford's rail pricing data base does not include information such as mileage for Mexican routes.
[38] The regression yielded the following for 86 foot cars:

650 +	2.00*miles +	130*days	-0.02 length*day +	0.00 * hundred lbs	- 3.05 * box cars per day
(3.54)	(6.69)	(2.48)	(-0.93)	(0.92)	(-0.43)

And the following for 60 foot cars:

-220 +	3.50*miles +	275*days	-0.40 length*day +	0.00 * hundred lbs	+ 50* box cars per day
(-0.35)	(4.16)	(2.00)	(-1.29)	(0.54)	(0.59)

[39] All cost data have been disguised

Equation 5-b For 60 foot cars:

Cost per box car on a given route =	\$675 +	\$2.00/mile +	\$75/day
(t-stats)	(3.31)	(6.18)	(1.85)
($R^2 = 0.670$)			

From these regressions we can conclude a few things. First there does appear to be a lower average fixed cost for the plentiful 60 foot cars. It is interesting to note that the per mile cost of transportation in 60 foot cars is higher than for 86 foot cars. One possible explanation for this is that 60 foot cars have historically carried heavier goods such as engines. In fact, many heavy commodities can only be shipped in 60 foot cars, because an 86 foot car filled with the commodity would exceed the weight limits on the existing track system. The average weight of a shipment in a 60 foot car today is 104,000 lb. whereas the average weight in an 86 foot car is only 33,000 lb. The most likely reason for this is that the railroads used to price the 60 foot cars higher on a per mile basis due to the greater weight, but that current pricing methods substitute car length in lieu of load weight.

Note that the coefficient for the number of days transit is only \$75 per day. This implies that the savings to be gained from reducing the transit time are small relative to the total cost. If FPS does drive transit times down, the savings in transportation will be small. The savings on a per mile basis can only be achieved through resourcing of parts to different supplier plants to alter the miles each part must be transported. Ford is currently investigating this possibility using a logistics modeling approach.

5.3 Equipment Capacity and Reliability Performance

5.3.1 How the fleet is sized

The number and distribution of rail cars allocated to Ford service by origin plant is determined based on the peak shipping volumes from the given origin[40]. The motivation for this is that during

[40] Ford analysts perform this analysis. This is in contrast to General Motors, where the railroads determine fleet capacity based on GM's stated demand

periods of sustained high demand there are sufficient rail cars to avoid deviating some shipments into trucks. Because of the long distances many rail normal parts are shipped and because of the high cubic volumes being moved, truck deviations are often very costly. In most cases there are actually more cars assigned to a given origin than peak volumes would indicated are necessary, yet plant and logistics personnel consistently feel that there is a "shortage of rail cars" particularly among 86ft box cars.

This seeming inconsistency can be explained by looking at the reliability and maintenance of the box car fleets. Based on data for Ford stamping plants from October through December the percentage of cars out of service for unscheduled maintenance is 8% (+/-1.23% at a 95% confidence level). All box cars are supposed to be removed from service once every 18 months for minor preventative maintenance. Suppose this maintenance removes a car from service for a week. If the proper maintenance schedule is followed, 1.28% of the fleet would be out of service for this maintenance at any given time. In addition to these minor maintenance services, all cars are supposed to be fully reconditioned every seven years. Suppose this takes an average of one month. Thus an average of 1.19% of the rail fleet will be out of service for major reconditioning at any given time. Between these two types of service, a total of 2.47% of the rail fleet will be unavailable at any given time.

To see what these numbers mean in terms of the effective capacity of the rail fleet, let us look at stamping as an example. First we need to understand how the size of a stamping plant's rail fleet is determined. To determine the number of cars required at a Ford stamping plant the daily volumes and transit times are calculated for all routes originating the given stamping plant. The daily volumes are based on the peak sustained volumes coming out of the stamping plant.[41] Each assembly plant has a peak demand, and the stamping plant's rail fleet is assigned assuming all

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[41]The peak demand from a given assembly plant is based on the line rate at which the assembly plant produces, and the maximum contractually allowable overtime. Typically a plant running a two shift operation can require the hourly workforce on each shift to work 10 hours per day during the week, and 8 hours for two out of every three Saturdays. This equates to an average of 110.7 hours per week of total work time, and 100.7 hours per week when break time is removed. An assembly plant with a line rate of 50 jobs per hour running a two shift operation would have an effective capacity of 5030 vehicles per week. A stamping plant supplying hoods to this plant would need to have enough rail cars available to ship 5030 hoods per week.

assembly plants require peak demand at the same time. Historically, many plants will run at or near capacity in March and April due to seasonal patterns of vehicle demand. The size of the fleet also depends on the transit times between the stamping plant and its various customers. To determine the round trip time to use when calculating fleet size, the standard one way transit time is doubled, and three days are added for "dwell time." This is to allow for time that the rail car sits idle in the customer and stamping plant yards. We can express this approach in the following formula:

Total Average Transit = (Loaded transit time * 2) + 3 days dwell

Equation 5-c

As mentioned above, the actual number of cars assigned to all of Ford's stamping plants is actually greater than the theoretical number that should be required based on the approach above. We notice that the formula for calculating the required fleet size does not include any allowance for cars out of service or undergoing maintenance. Let us assume that the maintenance schedules are followed, and that maintenance is evenly spaced through time so that there are always the same number of cars out of service for maintenance. (i.e. there is no variance in the percentage of the fleet out of service for scheduled maintenance.) If we assume that the percentage of cars on bad order status is a random variable with mean of 8%, we can calculate the effective service rate of the fleet during peak demand as follows:

Of the 3266 cars actually assigned to the Ford stamping fleet, 2.47% are supposed to be out of service at any given time, so the number of available cars is actually:

$$3266 \times (1-.0247) = 3185$$

At any given time, an average of 8% of these cars will be bad. The actual number will vary. Assume that the bad order cars are independently distributed, and that down time is one day. Hence, we can use the binomial distribution and estimate the variance in the number of bad cars as:

np(1-p)

where n=number of cars in the fleet

p=percentage of bad cars at any one time.

Variance = 3185 x 0.08 x (1-0.08) = 234 cars

sigma = sqrt(234) = 15.3 cars

What then is the effective size of our fleet? If we set the service level at 95%, using the normal approximation to the binomial, then the effective size of our fleet is 2907, which is 11% less than the 3266 we though we had. We determine the effective fleet size as follows:

Total cars available	- cars out for maintenance	- average on bad order	- 1.645 sigma bad order
3266	- 81	- 252	- 1.645 * 15.3 = 2907

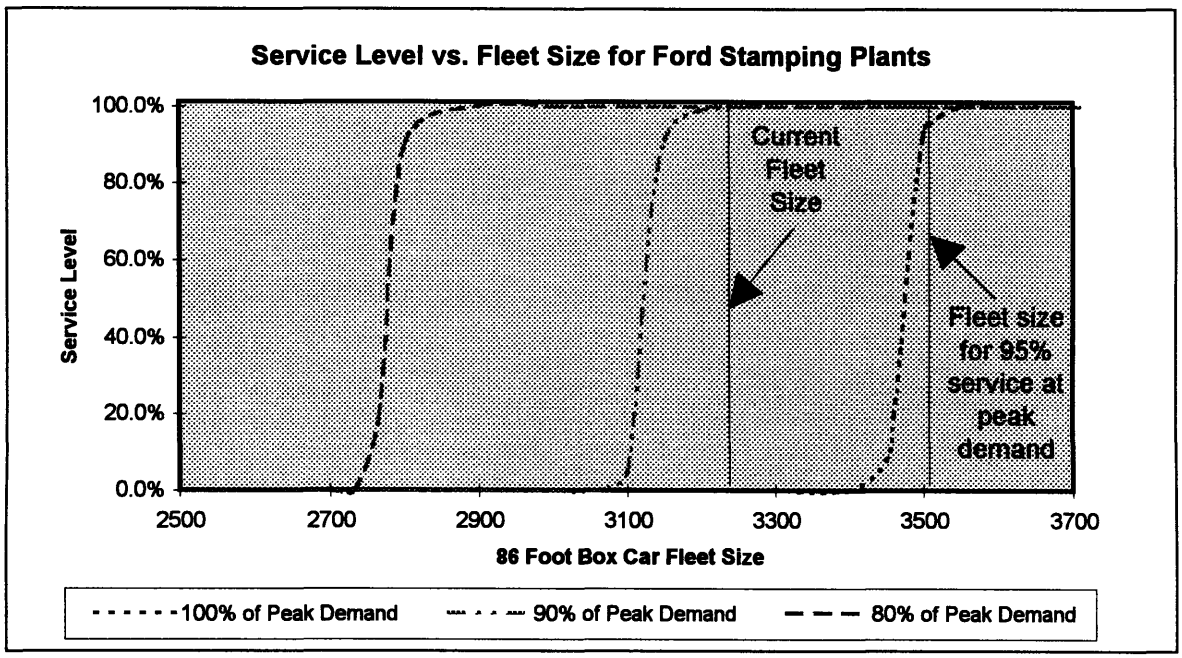

Figure 5-e - Service Levels vs. Fleet Size in Ford Stamping Plants

We clearly do not have the 3504 cars required to assure a 95% service level during peak demand. Figure 5-e shows how service level varies with the number of box cars assigned within the Ford stamping fleet. The three data sets represent the service performance for various levels of demand. 100% of peak demand equates to all assembly plants running at capacity. 80% of peak demand approximates all assembly plants running minimum schedules (i.e. no overtime). Note that for

80% and 90% of peak demand, the existing rail fleet performs at service levels of essentially 100%. This implies that the probability of having a shortage of cars when the demand is less than 90% is essentially zero. However when demand rises above 90% of peak, the service level drops dramatically. If all assembly plants were running at 100% of capacity, the probability of having a shortage of rail cars is essentially one. The fleet would need to have 3550 cars to ensure essentially 100% service levels at 100% of peak demand.

Although there is some seasonality in assembly plant operating patterns, it is more often the case that some assembly plants are running at peak capacity year round, and some are running with no overtime and several weeks of shut down each year. Thus we expect the actual demand level to be greater than 80% but less than 100% with a seasonal variability, and that there will be box car shortages as demand increases.

It is rarely the case that a given plant must deviate shipments to truck mode due to a lack of box cars. This implies that there is some correction going on to make more box cars available relative to the above analysis. In fact, this correction includes a failure to maintain box cars on the scheduled basis and an unwillingness to take cars out of service for repairs that are not show stoppers. (We will quantify this effect in the next chapter.) Not surprisingly, this leads to a poorly maintained fleet of 86 foot box cars. As we will see in later sections, maintenance related issues are one of the top concerns of rail users.

From the findings in this chapter we can draw three major conclusions regarding the logistics of rail transport. First, we see that there is a great deal of waste in the rail system. (i.e. time parts and equipment spend idle rather than moving from origin to destination.) Some of this waste arises from the need of the railroads to schedule in such a manner as to maximize their equipment utilization, while some arises from a lack of incentives to reduce certain wastes. (e.g low emphasis on rack return transit times.) Second, we see that equipment related decisions including the construction of specialized box cars will impact the logistics of the rail system and likely increase the level of waste. Unfortunately the third finding is that a regression based pricing model of rail

transport does not aid us greatly in determining the impacts of changes to rail logistics on the price Ford pays for rail service.

6. Equipment Design Issues

The issues of maintenance and fleet capacity are common to both the logistics of the rail system and the related equipment. In the previous chapter we alluded to regularly scheduled maintenance. In this chapter we will examine how "regularly" this maintenance takes place, and the impact on fleet performance. We will then examine the issue of the impact of creating unique equipment which is dedicated to a specific origin-destination pair, as a highly automated system is likely to be. From this we will make some inferences as to where it might be appropriate to design special purpose rail equipment.

6.1 Equipment Maintenance

Much of the frustration with railroad equipment centers around issues of regular maintenance. Plants that have instituted regular maintenance programs on box car doors claim a significant improvement in door functioning. It is widely accepted that production equipment will not function properly without sufficient preventive maintenance, and box cars are no different.

Figure 6-a below shows the status of the box cars in the stamping fleet (all box cars allocated to Ford stamping plants) with regard to preventive maintenance and major reconditioning. Preventive maintenance is supposed to be performed every 18 months and includes lubrication and adjustment of the doors, as well as other mechanisms in the box car. The major reconditioning is supposed to occur every seven years, and consists of a major rebuild of the car. Clearly a large portion of the fleet is overdue for one or both of these services.

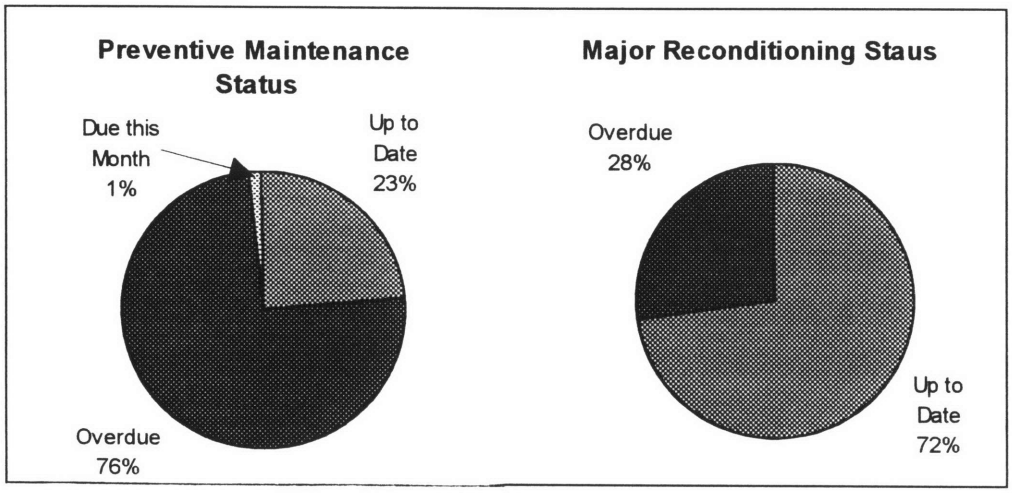

Figure 6-a Stamping Box Car PM and Reconditioning Status

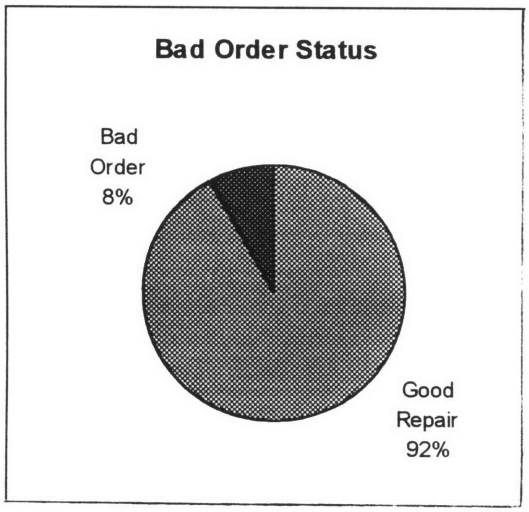

Figure 6-b Stamping Box Car Bad Order Status

Figure 6-b shows the "bad order" status of the cars in the stamping fleet. In railroad parlance, a car on bad order status has been removed from service for some repair. A car with doors that can not be opened, or are very difficult to open, may be put on bad order status. Similarly a car with a broken cushioning unit may be placed on bad order status depending on how bad the problem is. There are no hard and fast rules for when to put a car on bad order status. It follows then that the percentage of cars on bad order status is a function not only of the state of repair of the fleet, but the surplus of cars. If there are plenty of extra cars on hand, then a plant can place cars on bad

order status for less serious problems. If there are very few spare cars a plant is more likely to "limp along" with a poorly functioning car than to take a car out of service for repair. This trend is evidenced by the comparison of the stamping fleet (which consists of 86 foot cars which are in high demand) with the engine fleet (mostly 60 foot cars which are in plentiful supply.)

Note from Figure 6-c below that the engine fleet is much more up to date regarding preventive maintenance and reconditioning.

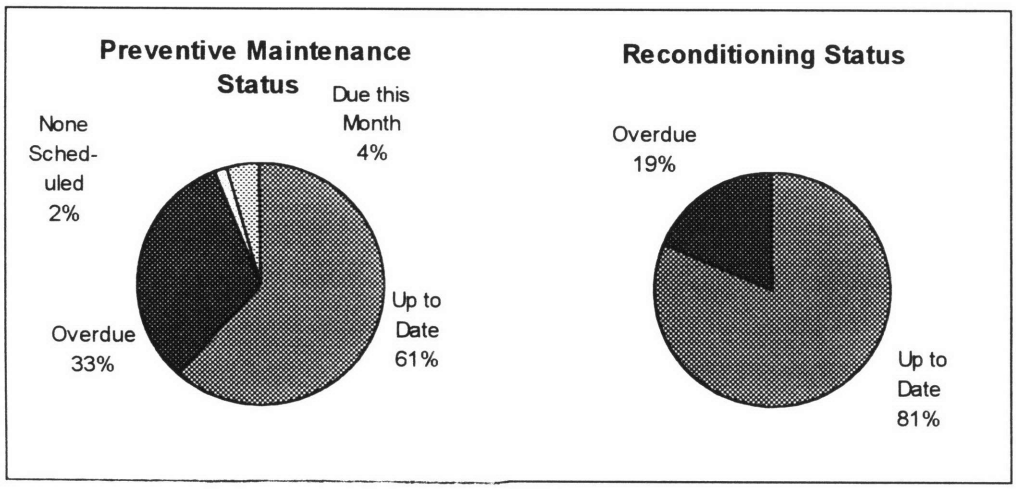

Figure 6-c Engine Box Car PM and Reconditioning Status

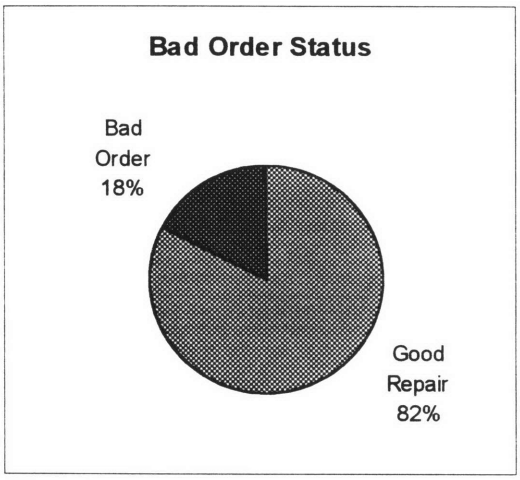

Figure 6-d Engine Fleet Bad Order Status

Figure 6-d shows the percentage of the engine fleet on bad order status. Note that although a higher percentage of the engine box cars are up to date for their preventive maintenance and reconditioning, there are a higher number of cars on bad order. One engine plant rail dock supervisor indicated that all box cars are inspected every shift for problems, and tagged for bad order if problems are found. This is in contrast to the stamping plant descriptions of placing a car on bad order only if the door can not be opened.

As noted above FPS requires reliable processes and zero defects. If rail is to remain a viable mode of shipment, the equipment maintenance issues contributing to unreliable access to delivered goods, and to transit related damaged goods must be resolved.

6.2 Cost of uniqueness

6.2.1 When is a car unique

If we are considering modifications to the physical structure of a rail car, we must attempt to gage the cost of this uniqueness. In some situations, the additional cost of managing a unique car is low (for cars that become naturally captive as described above.). In others additional managerial effort will need to be made to track and route the unique cars correctly, with some associated cost. It is worth noting that all cars that contain either full or empty racks are to some degree unique. A box car only becomes truly "generic" when it is completely unloaded.

If we were to design significant uniqueness into a new box car, we would not only have greater management costs but we would need to size the fleet to provide the desired service level. Using a similar approach to that in section 5.3, we would optimize fleet size based on failure and repair data for the new design to attain a given service level. The example below illustrates how the number of box cars that must be kept on hand as "safety stock" varies with the level of uniqueness and the demand variability.

Suppose that we have one stamping plant supplying ten assembly plants. For simplicity assume that each assembly plant has a demand of 100 ± 15 box cars per day worth of material. If any box car can be shipped to any assembly plant, then the demand for box cars will be: $1000 \pm \sqrt{150}$. If, however, each plant requires a unique box car, then the demand will be 1000 ± 150. If we want to protect for demand to the 1.645 sigma level (95% service level) we would need a total of 1021 box cars in the first case, and 1246 in the second case. The effect of car uniqueness depends on the variability of demand since unique cars can't be substituted with other cars. When selecting a pilot route for a unique car design we will want to choose one with low demand variability, and closely coupled material flow at both ends.

In this chapter we have seen that regularly scheduled maintenance does not often occur on schedule. This finding may explain why so many rail customers were dissatisfied with the condition of rail cars, and why issues like door reliability and cushioning unit performance were of such concern. We have also shed some light on the apparent contradiction between the method of sizing the rail fleet (which first appears to allocate more cars than needed) and the perceived "shortage" of 86 foot box cars. Because the fleet sizing methods do not take into account the variability in equipment reliability and the loss of fleet capacity to preventive maintenance, the total number of box cars allocated to Ford service will not suffice during periods of high demand. Finally, we have seen that if we are going to implement specialized equipment there are certain conditions under which the impact on rail logistics will be minimal.

7. Recommendations, Reflections, and Conclusions

In this chapter recommendations for equipment designs and logistics system analyses will be presented. We will then reflect upon the pros and cons of applying a product design oriented customer needs analysis to an internal development project. Finally we will conclude with a high level summary of the findings of this research and their implications.

7.1 Equipment Design Concept Recommendations

The following are equipment design concepts for bringing rail shipping into closer alignment with Ford's strategic objectives, as well as for addressing the identified customer needs. All of these concepts received favorable feedback from plant personnel, and were generated with the input of representatives of Norfolk Southern and TTX-Drayco.

7.1.1 RF Tag scanners

In the customer needs analysis we identified that accurate and error-proof information systems for identifying car contents were a top want. We have also identified that from the point of view of strategies like ILVS and FPS, accurate information is a must. Plant personnel describe the inaccuracies in the record of car contents coming from human error or lack of willingness to input any information at all. A box car number might by typed into the shipping system incorrectly, or an assembly plant might not take the time to identify the type of rack being returned, or mistake empty left hand racks for empty right hand racks.

One concept for addressing this issue involves the use of radio frequency (RF) tags attached to the shipping racks, with RF scanners mounted dockside near box car door openings. A fork truck driver loading racks into a box car would drive by the scanner on his way into the car, and the contents of the rack would be added to the contents list for that box car. Box cars themselves all have RF tags mounted on their sides, called Automated Equipment Identification (AEI) tags. The dockside scanner could read these tags as the box cars were pulled into the plant, add the cars' contents to the plant inventory as the racks were unloaded, and refill the car as new racks were loaded.

Existing "cubing" software can provide material handlers with a layout of the optimal arrangement of goods in a conveyance, and store this layout. If this information can be compiled automatically when a supplier is loading the box car, an unloading sequence and map can be created to facilitate ILVS shipment of parts. If a system like this were installed in a plant with a highly automated material movement system, such as the Twin Cities assembly plant, it could be integrated with existing material replenishment systems.

The pros of this concept include the ability to generate bills of lading and advance shipping notices automatically. Although the process differs from plant to plant, all supplier plants have a process for tagging racks of outgoing material when they are produced, and then transferring part information to a shipping notice. This requires the time of the material handlers and/or material control personnel, and has great potential for error. Automating this process would both save time and increase accuracy.

The drawbacks of this system include the risk of malfunction that customers fear. Current RF tags lack the range to function in this application, but development of longer range tags is underway. The largest barriers to implementing this concept may lie in the initial investment costs for equipping a large rack fleet and installing readers. As costs for the longer range tags become more clear, the cost of installing an RF tag on a rack should not only be compared to the cost savings of reduced labor and inaccuracies, but to the costs saved by eliminating the single use bar coded tags currently printed to identify material.

7.1.2 Improved door designs

As discussed above door maintenance was considered a major issue by all of the plant personnel and by some of the staff personnel as well. Discussions with plant and railroad representatives indicate that the two major sources of door damage arise from lack of proper maintenance and improper operation of the doors. When a door is not properly adjusted and lubricated, the force required to open it may exceed the strength of an average material handler. This leads to using the fork of a fork lift truck to force the door open, which worsens problems of adjustments. One solution to this problem is to perform maintenance on the doors at more regularly scheduled

intervals. A second solution is to design out the need for lubrication and adjustments in the doors themselves.

Designs exist for less maintenance intensive, more robust doors. One type, the top hung sliding door, is currently in service on some Conrail cars with positive results. This type of door slides on fully enclosed rails at the top of the door. The full enclosure prevents dirt and debris from getting in the rails, and keeps lubricants in the moving mechanisms. The bottom of the door rides in guides which prevent the bottom of the door from swinging away from the car, but which carry none of the load of the door. If a ford truck driver hits the door from the inside of the car, the bottom of the door will pop out of the guides (which can be reset with relative ease) instead of damaging the door and its alignment.

The advantage of this door design is that it reduces serious damage to the door upon impact, and that it requires less maintenance. One disadvantage of this type of door is that it does not provide as tight a seal to the car as the standard "plug" type door.[42] Norfolk Southern engineers are currently attempting to develop better seals for sliding doors. If maintenance continues to be performed at or below the required level to keep equipment functioning, installing new doors may have little or no impact other than to slightly reduce the amount of preventive maintenance on box car doors, while requiring the same amount of corrective maintenance. Stated differently, when rail users say, "We have door maintenance problems" a distinction needs to be made between door problems, and maintenance problems. The slider door may be a solution to the door problem, but not to the maintenance problem.

Composite doors were also suggested as way to reduce door damage. The premise is that if the doors are lighter, material handlers will be less likely to use excessive and damaging force to open them. The primary downside of composite doors is the cost. Not only is the initial fabrication cost higher than for a steel door, but the cost of repair where repair is even an option is high.

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[42] A plug type door actually compresses a seal against the door opening in the box car to provide a weather tight seal. The mechanics of this motion are in part what make plug doors require adjustment. A slider door in contrast simply slides over the opening in the box car.

7.1.3 Containerized loads with automated transfer

One concept that met with enthusiasm at more technologically sophisticated plants and great skepticism at less technologically advanced plants was the idea of shipping in ISO-like containers. These containers would be automatically transferred from flat cars to in-plant use. Either standard ISO containers (20 or 40 feet long) or smaller custom built containers would come into the plant on container (flat) cars. These containers would be transferred laterally off the flat cars onto the dock. There they would either be opened and unloaded automatically or transferred to the point of use within the plant.

TTX envisioned a system where a chain drive system was installed in the floor of the container. When both doors on the container were opened, goods could be through loaded or unloaded with the aid of the drive system. Once removed from the container, the goods could be laterally transferred to tow dollies pulled by AGVs to be delivered to line location.[43]

This system has the advantage (over modifying existing 86 foot box cars) that ISO containers are in relatively plentiful supply. Because containers have smaller and simpler doors, they are less prone to maintenance problems. If containers even smaller than the smallest current container are used there is the possibility of replacing racks with small containers. By containerizing the loads, parts from different suppliers can be shipped in smaller batches on a more frequent basis than if a supplier must fill an entire box car before shipping. Although this ranked low on the stated customer needs, small batches is part of the longer term strategy inherent in FPS. If done well, this system has the potential to reduce the material handling labor cost component of the total cost of rail.

The disadvantages of this system include the need for more dockside space, the loss of cube relative to box cars, the risk of lost production due to system downtime, and the potential to

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[43] A system incorporating many of the features of this concept exists at the Twin Cities assembly plant. Material is moved on wooden slave pallets through a series of driven rollers.

increase total cost at the expense of reduced labor cost. This system by itself does not address issues of information accuracy, but the RF tag concept could be integrated to address this issue. Major plant equipment investments are likely to be required. If this option is pursued further a thorough cost study addressing the categories of total cost as outlined in section 3.3.2 is essential.

7.1.4 Preventive Maintenance Schedules and Equipment

As described in section 6.1, preventive maintenance schedules must be adhered to if rail is to remain a viable mode of shipment. Not only should maintenance be performed on a well crafted schedule, but devices that assist in performing P.M. should be seriously considered. One example has to do with the fluid cushioning units used to reduce the impacts of coupling cars. These devices are essentially fluid shock absorbers. As with any shock absorber, if all of the fluid has leaked out, there is almost no damping effect. Current cushioning units have no means for checking fluid level. Keystone has developed a cushioning unit that can be monitored for low fluid levels and can send a signal indicating the need for maintenance. Insofar as devices such as this allow for the more proactive maintenance policies such as those in some engine plants, they should be considered for installation in light of the issues of FPS, ILVS, and the like.

7.2 Logistics System Recommendations

7.2.1 Further characterize time and cost distributions

The process flows in 5.1 illustrate the distribution of time in the rail system. The characterizations within this thesis describe this distribution at a rather highly aggregated level. Although it is useful to know that the rack return transit is greatly in excess of the loaded transit, we would like to better understand the reasons for this. Future study of this matter should attempt to characterize the rail shipping process in the time domain at a more detailed level than is done herein. For example if we knew how much time a box car spent actually moving along rail lines, versus waiting in a classification yard, we would be better able to identify areas for eliminating waste from the rail process.

In section 3.3.2 we discussed the components of cost that figure into the total cost of rail shipping. Each of these costs can be mapped to a step in our rail process flow. By identifying the distribution of these costs we would better know where to focus reduction efforts.

7.2.2 Continuous improvement teams to reduce waste

Once we have identified the cost and time distributions within the rail system, we need to put systems in place to begin the process of removing waste from this system. There have been single instances of representatives from Ford and the railroads working together to develop "fast trains" which eliminate much of the waste, but these have been isolated instances. If waste is to be removed from the rail system in a sustainable manner for the railroads, these teams must consist not only of representatives from transportation procurement and a single railroad, but from rail served plants, from short and long haul railroads, from logistics planning, from FPS, and the like. If Ford truly wants a more lean transportation system then the metrics and incentives must reflect this. If we continue to pressure railroads for faster loaded transits while ignoring return transit times, we should not be surprised when we get return transits that are twice as long as loaded transits.

7.2.3 Decision Making Processes

As discussed in section 3.3.2, the decision making process for truck vs. rail needs to be better defined in light of new strategic objectives. A rational decision making process requires prioritization of strategic directives. Situations will arise where trade-offs must be made, and analysts will need a guide for these decisions. For example, if there are two transportation options, one of which exceeds the six day order to delivery window, but which saves $500 per move, which one should be chosen? To make decisions such as these, Ford needs to know which constraints must always be binding, and how to compare options for non-binding constraints. This may imply setting thresholds (e.g. We will pay an extra $200 per move to stay within the six day window, but if the savings are greater than $200, we will protect the assembly plant sequence with inventory.)

A logical next step in refining the decision making process would be to evaluate the proposed cost model in a variety of different transportation situations. One approach to this would be to plug

various scenarios into the model and determine what shipment characteristics most greatly influence the truck vs. rail decision. Statistical analysis of the results of these scenarios characterize those shipment characteristics which most influenced the truck vs. rail decision.

A second approach would be to restate each element of the cost model in terms of shipment characteristics. For example, transit cost might be a function of distance traveled, cubic volume, weight, and the like. We can use regression analyses similar to those in section 5.2.1 to determine the specific nature of these functions. With this data in hand, we could describe the cost of shipment purely as a function of shipment characteristics, and see which components contributed most greatly to the total cost, and where the breakpoints lie. This would allow us to provide logistics analysts with sound cost decision making tools.

7.3 Reflections on Internally Applied Customer Needs Analyses

This thesis describes one attempt to apply the principles of product design methodology to a project within a company. The application of a structured analysis method to the problem of rail transportation proved to be useful in some areas, but insufficient in others. Following are the author's thoughts on the benefits and drawbacks of applying a product design methodology to an internal development project.

7.3.1 How customer voice can better define the problem

The distinction between symptoms and underlying problems may be a difficult one to draw. System dynamics models of complex systems illustrate the non-obvious nature of many underlying problems. By soliciting and documenting "customer" (stakeholder) input, the underlying problems can be better defined. In the case discussed in this thesis, customer input was initially sought on the subject of box car design for automation, because the project was defined to address problems of labor costs and automated material flow. Discussions with various customers of rail pointed out that concerns over system wide logistics and existing equipment reliability overrode the desire for automation technology. As a result of this input the project scope was broadened to include logistics as well as equipment.

The results of the customer needs survey indicated a rift between the stated strategic goals of the organization (lean manufacturing a la FPS, for example) and the stated wants of the rail users (where small batches and frequent deliveries ranked low). Although the use of a documented customer needs analysis brought this dilemma to light, the traditional product design methodology does not tell us how to evaluate this type of conflict. In product design, the fundamental assumption is that no one knows better than the customer what he or she needs. Although it may be a product developer's job to elucidate latent needs, it is not often the case that a product is "forced" on a customer. This assumption does not seem to hold for projects within a company that challenge existing paradigms.

In the case of railroad equipment and logistics design, it seems that many of the customers were asking for improvements to the status quo, or incremental innovation. Yet the high level strategic objectives seem to demand more radical change. The product development process does not tell us much about how to develop radically different systems that meet with operational resistance by challenging long held paradigms. True, we may be able to use information gathered from customers to incorporate features into radically different systems to "ease the pain" of a totally new way of doing things, but we run the risk of alienating our customers. For example, if all of our customers said, "We really do not want a system that forces us to ship in small batches, but we really do want more reliable doors" and we gave them a system that had reliable doors but forced small batches, how much credibility would we have when approaching these same customers and seeking their input on a subsequent project?

When a customer's input is actively sought in a formalized process such as a customer needs analysis, there may be an implied contract to make a good faith effort to meet the customer's needs. Failing to do so (or worse actively going against the customer's needs) threatens the open dialog between those responsible for developing new systems and those who will have to live with the changes. Although there is a risk of alienating customers by failing to address their needs, the customer needs analysis process may have the benefit of bringing previously unraised issues to the attention of those developing and decreeing the strategic goals.

7.3.2 Customer hierarchy and definition is important

Because the application of a product design/customer needs methodology to development projects within a company may highlight conflicts between strategic objectives and operational wants, it may be prudent to identify a hierarchy of customers before beginning the analysis. For example, we might want to identify up front that meeting the strategic objectives of the Ford Production System is our top need. Then a customer needs analysis could approach the operational customers with the clear understanding that small batches and frequent shipments are the way of the future, but that user input is required to figure out how to best implement this aspect of FPS.

Existing product design methodologies tell us to begin with a mission statement that explicitly states the objective of our development project. We might have a mission statement that talks about building a better mousetrap, and we would look to our customers to tell us what "better" means. If we set our mission to design a better box car, or a better rail logistics system, our customers may not have a common vision of what "better" means. Product design philosophy gives us tools for prioritizing customer needs based on the strength and number of customer sentiments on a given issue.

The underlying assumption here is that we will design our product so as to please the greatest number of people the most, and that it is acceptable to alienate a small number of customers to please the many. In other words, there is an assumption that a customer can choose not to buy our product. In the case of internal development projects, the people we have identified as customers can not choose to simply not use the resultant product of the design effort. Internal design projects require the designers to live with the dissatisfied customers. Customers whose needs have been ignored are going to be unhappy, and potentially destructive to the project success if a design exacerbates rather than solves their problems.

It is this lack of choice which makes the application of product development methodologies to intra-company development projects a challenge. One way to address this issue is to determine the relationships between customers before beginning any customer needs analysis. If we intend to

compile a survey ranking potential system features from critical to unacceptable, we can establish at the outset the rules for weighing various groups' input. For example, we might say that if a given system feature is critical to the strategic group, and undesirable to the operations that we will consider it to be more or less a critical feature. At the same time we might decide that a feature which is desirable to the strategic group, but unacceptable to the operations group would be considered basically unacceptable.

The process of deciding in advance how different customers' needs will be weighed would require assembling a team of representatives from many different functions to negotiate these weightings. It may be these negotiations which prove to be the most difficult stage of the process. The debates during such negotiations may bring up fundamental questions like, "Who best knows what the future of our business will look like- the strategists or the operations people?", and "How and when do we introduce new and unpopular ways of doing things to our operations?" The application of a product design methodology to an internal company development project may help bring many of the underlying issues to light, but does little to suggest ways of resolving these issues.

7.4 Conclusion

At the outset of this thesis we asked the question, "Why are the logistics and equipment of the railroads an increasingly poor fit to Ford's needs?" The most general answer to this question appears to be that rail has not been subjected to the same kinds of continuous improvement efforts and lean-thinking scrutiny as plant operations and, to some degree, truck transportation. Examples of this lack of leanness include the large number and size of "buffers" in the rail system in the form of switching yards; the lack of adherence to preventive maintenance schedules and practices; the lack of standard operating procedures in making rail transit decisions; and the lack of discipline in on-time delivery.

Having identified the reason for the poor fit between rail and Ford's new strategies, we sought ways to improve the fit to capitalize on the advantages of rail. The most obvious way in which we

can improve this fit is by applying lean manufacturing techniques to rail transport. The first step in doing so requires characterizing the current system. We have seen a characterization of the current system in the time domain, and have recommended further characterization in the cost domain. Once the system is characterized, activities that do not contribute to delivering good parts to assembly plants at the proper time and with the lowest possible cost must be reduced or eliminated.

Standard operating procedures need to be developed for making truck vs. rail decisions, for managing the flow of materials and information in the rail system, and for the movement of rail cars through the rail network. We have discussed one method of standardizing the transportation mode decision making process, and identified the need for further study of this matter.

At the most general level we conclude that if rail is to remain a viable mode of shipping from component to assembly plants, both Ford and the railroads must behave and manage as lean organizations.

Bibliography

Barnhart and Ratliff, "Modeling Intermodal Routing", Georgia Institute of Technology, December 1991 COC-91-11

Bhatti, Garg, "Review of Railway Vehicle Performance and Design Criteria", International Journal of Vehicle Design, Vol. 5, Issue 1-2, January 1984, p.232-254

Cobb, Chris and Redding, David, "Maintenance Investment Safeguards Capital Outlay", Railway Gazette International, Vol. 148, No. 2 (February 1992) p. 105-107

Delany, R. "Trends in Logistics and US World Competitiveness", Transportation Quarterly, Vol. 45, No.1, 1991, p.19-41

Down, Wise, "Domestic Containerization: Overview of Terminal Design and Operating Issues", Transportation Research Board State-Of-The-Art Report Issue No. 4, 1986 p.116-122

Draper, Gary, "New Opportunities for Savings in and Evolving Transportation Environement", National Meeting of AIChE, 1986 Annual Meeting, Paper 92C

Etwell, MJW, "Advances in Rail Wagon Design". Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit, Vol. 204, No. 1, (1990) p.45-54

Engle, Tom, "Iron Highway Tests Prove Integral Trail Concept", Railway Gazette International, Vol. 150, No. 5, (May, 1994) p. 295,297+

Frost, William, "Changes in the US Rail Transit Car Manufacturing Industry", Transportation Research Record, 1984, p. 4-23

Harker, Hong, "Pricing of Track Time in Railroad Operations: An Internal Market Approach", Transportation Research. Part B: Methodological, Vol. 28, No. 3, 1994, p.197-212

Hawthorne, Fisher, "Progress in Railway Mechanical Engineering: Cars and Equipment", Americam Society of Mechanical Engineers Report No. 80-WA/RT-11 Conference Paper, 1980

Hogan, Rey, Faas, "Design of a Smart, Survivable Sensor System for Enhancing the Safe and Secure Transportation of Hazardous or High Value Cargo on Railroads", Proceeding of the IEEE/ASME Joint Railroad Conference (1994), p.147-152

Leedham, Sfirakis, Spearin, "Development and Testing of a New Generation Two-Piece Bulkhead Door", RTD Rail Transportation Proceedings of the 1993 Ride Quality Conference of the ASME, 1996, p.37-51

Marin, Salmeron, "Tactical Design of Rail Freight Networks. Part I: Exact and Heuristic Methods", European Journal of Operational Research, Vol. 90, No. 1, April 1995, p.26-44

Martland, Little, and Sussman, "Service Management in the Railroad Industry", Transportation Research Board Conference Proceedings 2, (1994) p. 89-103

Punwami, Swamidas, "Progress in Railroad Freight Car Engineering", RTD Rail Transportation Proceedings of the 1994 International Mechanical Engineering Congress and Exposition", p.89-108

Scales, "Design of Hydraulic End-of-Car Cushion Units for Shock Free Train Action", ASME Rail Transportation Spring Conference Proceedings, 194, p.29-40

Singh, Irani, Punwani, "Truck Suspension Specification Automobile Transport", Proceedings of the IEEE/ASME Joint Railroad Conference (1994) p.133-139

Stenger, Beler, "Effective Carrier Marketing Strategies: The Case of the Railroads", Transportation Journal, Vol. 15, No. 4, 1976, p.63-72

"New Standard Boxcars", Progressive Railroading, Vol. 16, No. 6, 1973

"Linking Car Design to Customer Needs: Engineering, Maintenance Capabilities Enhance Itel Rail's Position in the Car Leasing Field", Modern Railroads, Vol. 46, No. 4 (1991) p. 35-39