Information Technology Applications in Intermodal Terminal Management: A Systems View

by

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B.S., Civil Engineering,
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Submitted to the Department of Civil & Environmental Engineering and
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ABSTRACT

Information technology applications can provide more accurate information and promote information sharing within the intermodal transportation system. Investing in IT can therefore be a key method for improving intermodal terminal management. Compared to infrastructure construction, IT and information systems are relatively inexpensive, faster to implement, and free of environmental impacts. Thus IT applications could be helpful for a major problem in intermodal networks: increasing the capacity of intermodal terminals to meet growing demand.

This paper proposes an Intermodal Terminal Management Information System (ITMIS) that includes a central database and modules for data entry, queries, reservations, and terminal management. ITMIS also incorporates automatic optimization software. Effective communication technologies in ITMIS allow precise and accurate data entry and information sharing.

Depending on the extent of coordination among transportation companies, ITMIS could be useful at three different levels: 1) Management of an intermodal terminal—ITMIS could help managers to make better operation plans and schedules, monitor terminal processes more effectively, increase resource utilization and provide better customer service; 2) Coordination among the intermodal terminals, carriers, and customers—ITMIS could help "just-in-time" pickup and dropoff become feasible and help terminal managers to adjust peak demand with pricing strategies; 3) Information sharing among regional terminals—ITMIS could help terminals to work as a virtual large terminal, sharing equipment, storage spaces, or other resources and obtaining a better system optimization.

Queuing theory and results of previous research are used to estimate costs and benefits of ITMIS for a sample large terminal with annual throughput of 400,000 containers. With about \$1 million total investment, the system could help increase terminal capacity by 5~10%, while providing benefits with a net present value of \$3~7 million.

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Purpose of the Research

With steadily increasing demand of intermodal freight transportation all over the world, industry and government are concerning that intermodal terminals are going to reach their capacity limit and become bottlenecks of the whole intermodal transportation network. Infrastructure construction could possibly solve the capacity problem, but it takes a long time, costs a lot of money, and may have environmental impacts, such as noise and air pollution. So, over the next 5 to 10 years, most intermodal terminals may have to operate within the current facilities. For this reason, we need to investigate other methods to resolve the capacity pressure on intermodal terminals. Improving information systems is an excellent, inexpensive strategy. Better information systems can help to integrate intermodal network, improve the performance of links and connections, and improve the performance of the whole intermodal network system. Information sharing could be helpful because some components are working separately and are not well coordinated in current intermodal systems. Individual companies seek to optimize only one or two network components, and network components are considered independently from each other. Thus, a complete view for the whole network is usually omitted. In order to achieve optimization of the whole intermodal network, information sharing within the whole intermodal transportation system is necessary, and better partnerships among the different components of intermodal networks need to be developed.

Partnerships and information sharing are more significant in intermodal terminals than in other parts of the network, because intermodal terminals are intersections of different transportation modes, where cooperation is obviously more important. The key to improving performance of intermodal network in a relatively short time is to upgrade the coordination among the different transportation modes. It could be very helpful to develop an integrated information system to gather real time information automatically and to share information among terminals and transportation companies. Intermodal terminals are excellent places to implement advanced information technologies because of their connection functions in intermodal networks.

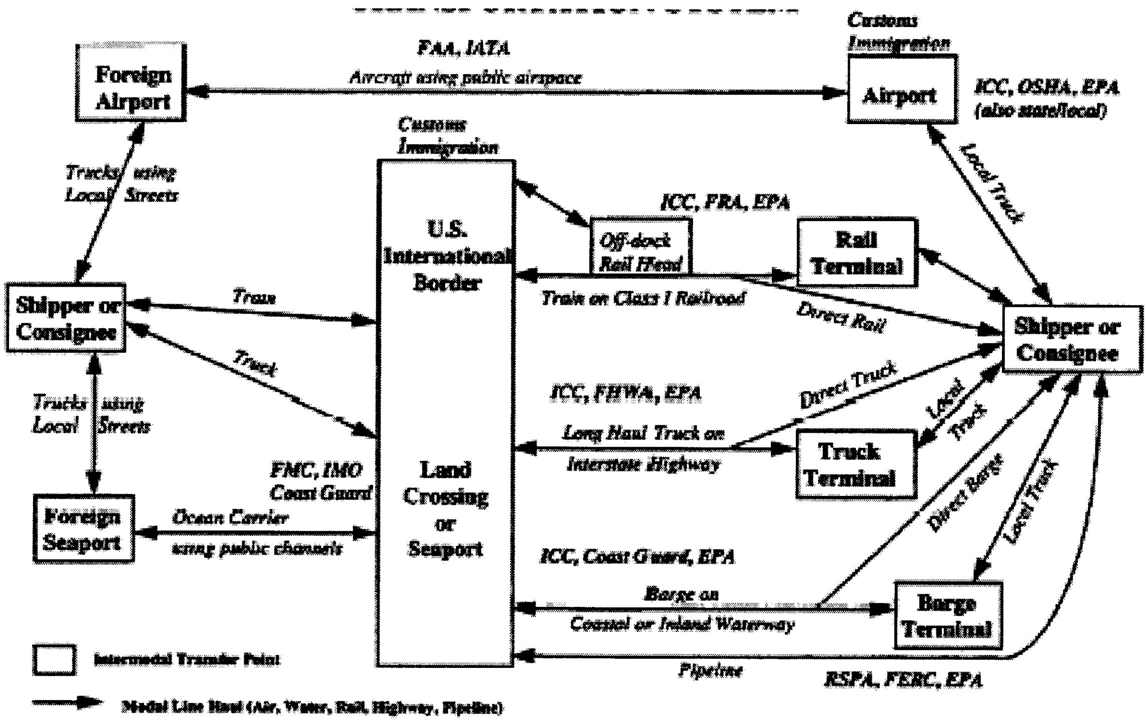
Most previous and current researches are concentrated on specific technologies or focus on a single transportation mode; more work needs to be done from a systems view. Hence, our research objectives are to design an intermodal terminal management information system, investigate capabilities of state-of-the-art information technologies to ensure the performance of the information system, and analyze potential benefits of implementing such a system on intermodal freight terminals.

Some research is already being done for building partnerships based on policy and strategy issues. [GDMS99] [PPEF00] In this paper, I therefore assume that policy, guidelines, legislation and other legal issues, institutional issues, community involvements, etc. are available to build partnerships. My focus will be on information systems and technologies, which may be implemented in the next 5 to 10 years.

1.2 Background and Problem Description

1.2.1 Intermodal Freight Transportation

Intermodal freight transportation is the movement of freight by the coordinated and sequential use of two or more modes of transportation. Intermodal freight moves from a shipper to a receiver by multiple modes through transfer points within a system. The Bureau of Transportation Statistics publication Transportation Expressions defines intermodalism as follows: “In its broadest interpretation, intermodalism refers to a holistic view of transportation in which individual modes work together or within their own niches to provide the user with the best choices of service, and in which the consequences on all modes of policies for a single mode are considered.” [TEBT96] Each mode of transportation has its own advantages and disadvantages. The various modes differ in terms of cost, speed, capacity and flexibility. In order to provide door-to-door transoceanic service, the cooperative partnership of more than one mode is inevitably required. Most international cargo moving to and from North America has to move intermodally. As stated in the ITS Joint Program Office report of US DOT, "The basic premise of intermodalism is that, under a well-integrated transportation system, the various modes work together to provide the user with better choices of service." [ITSJ96] Figure 1.1 gives an overview of international intermodal transportation flow, which includes various modes of transportation--air, rail, truck and water, as well as their connections.

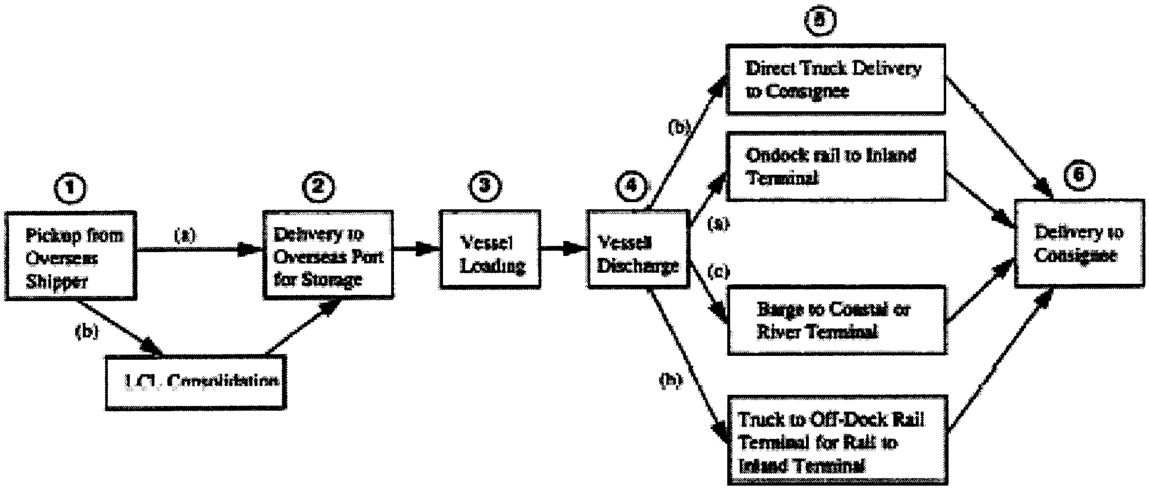


Source: Volpe National Transportation Systems Center, 1996 [ITSI96]

Figure 1.1 An Overview of International Intermodal Transportation

For example, in a truck-rail intermodal movement, a motor carrier picks up the cargo, which may be in a container or an intermodal trailer, from the shipper. Then the carrier transports the container or trailer and transfers the cargo to a railcar in a rail terminal. The railroad transports the container or trailer to another intermodal rail terminal where a second motor carrier picks it up and delivers it to the receiver or consignee.

Shippers use intermodal transportation if there is no single mode of transportation connecting an origin with a particular destination, thus virtually all overseas transportation requires intermodal connections. A shipper may choose multiple modes of transportation to avoid being dominated by a single mode or carrier, thereby reducing transportation costs, increasing transportation options, and taking advantage of special opportunities. Figure 1.2 shows an example of intermodal shipment, in which water is the first transportation mode and is connected to rail and truck mode.

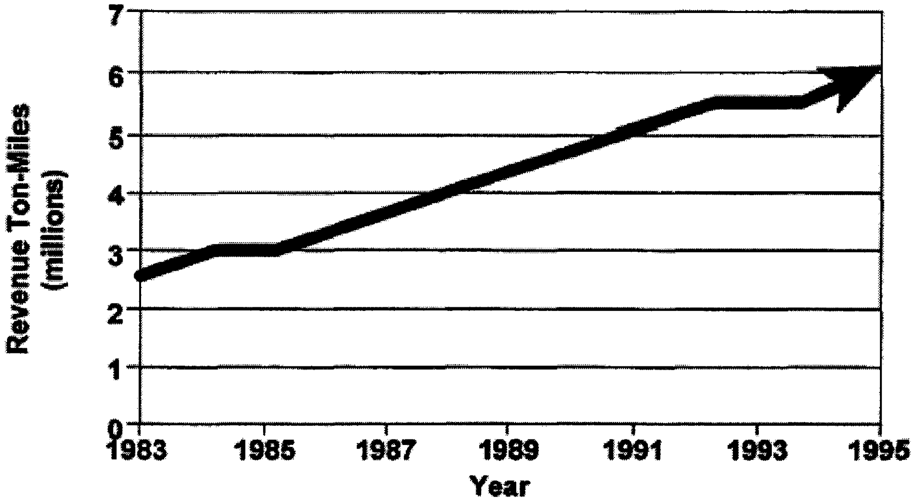


Source: Volpe National Transportation Systems Center, 1996 [ITSI96]

Figure 1.2 Sequences of a Sample Intermodal Freight Movement

Despite intense competition between modes, carriers also use intermodal transportation when it suits their purposes. For example, J. B. Hunt Transport, one of the leading nationwide truckload carriers, formed a partnership with railroads to provide Trailer-on-flatcar (TOFC) service and use railroads for line haul piggyback service. [DJBH96] This is because the long-haul motor carrier industry has experienced a high turnover rate of truck drivers, along with the high cost of training new drivers. Through cooperation between trucking companies and railroads, vehicle accidents and liability insurance expenses decrease significantly; fuel and tire costs as well as other truck and trailer maintenance costs have decreased; costs of repositioning empty trailers are also reduced. For these reasons, cooperation with railroads enables the trucking firms to serve new markets with fewer drivers and attain better equipment utilization. From the view of the railroads, the partnership with truck carriers has enabled them to reclaim some of the merchandise traffic. In addition, the Federal Railroad Administration estimated in 1991 that intermodal rail service was 1.4 to 3.4 times more fuel efficient than trucks, [ITSJ96] thus the energy saving is another advantage for advocating rail intermodal instead of single truck mode.

Another driving force behind intermodalism is economics. Figure 1.3 shows the steady growth of revenue for intermodal rail as ton-miles per railroad employee from year 1983 to 1995. The development of the double-stack train concept was a major factor to make shipping companies use railroads as a land bridge to connect port and port. In addition to lower transport costs, the shipping companies could obtain faster transit time and better vessel utilization. Transportation companies can serve new customers or open potential new markets for their existing customers through intermodalism. For example, railroads may create a truck-rail terminal to retain the business of existing customers located on a branch line which is currently lightly used or to be abandoned, or to serve a new off-line customer if there is enough traffic to justify the cost of constructing a new rail to the plant.



Source: Association of American Railroads

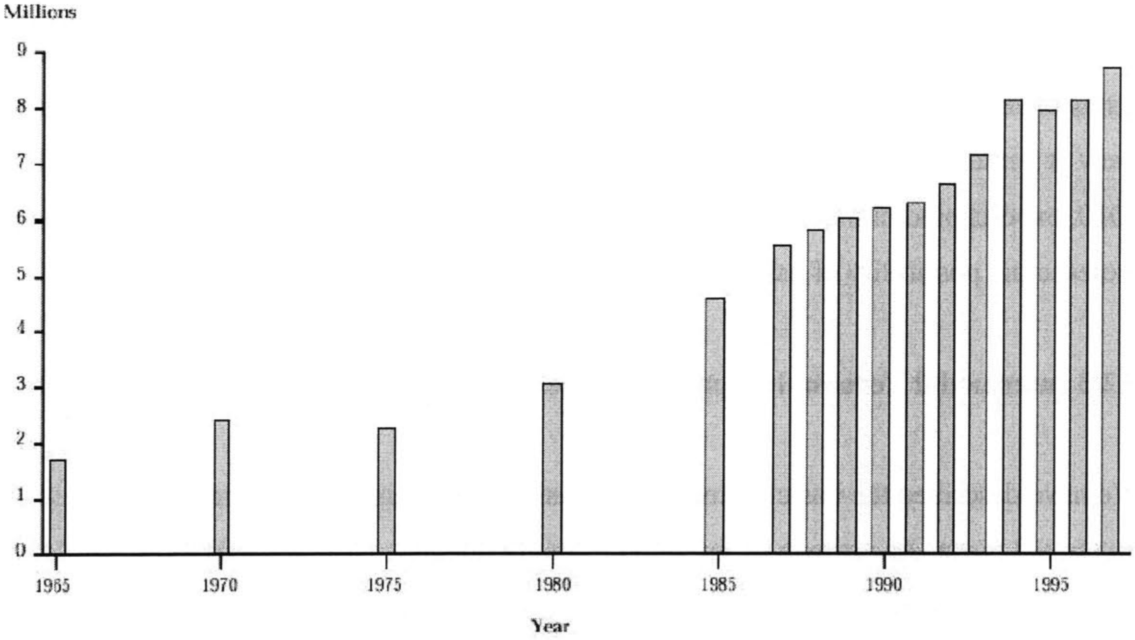
Figure 1.3 U.S. Intermodal Rail Productivity Advances

Intermodalism has become an important part of freight transportation in the United States. Carriers and shippers have recognized the benefits of integrated and coordinated transportation services and have made progress toward intermodalism. A vast industry devoted to intermodalism has been developed, including intermodal equipment manufacturers, leasing companies, and various intermodal service providers and facilitators.

1.2.2 Growth of Intermodal Freight Demand

Historically, there have been many impediments to intermodalism. The following are some representatives: regulations block cooperation between modes; each mode has its own capacity, flexibility, and quality of service; equipment is not standard; transit time may be longer than single mode transportation because the cargo transfer method is not efficient; more damage may occur because of additional cargo handling; communications between modes are not effective; cooperation and coordination between modes and among multiple companies are not enough; competitions between modes. Through policy reforms and technological improvements, many of these impediments have gradually been either partially or completely overcome. More and more companies have realized the potential benefits of better cooperation between modes. The importance and benefits of intermodalism, combined with obstacles being at least mitigated, have made the intermodal transportation increase steadily in the last several decades.

Intermodal traffic on U.S. railroads tripled over the last two decades as shown in Figure 1.4. The statistics of Association of American Railroads shows that the volume of international containers, domestic containers, intermodal truck trailers, and roadrailers handled by the railroads grew from 3.0 million to 8.7 million over the last two decades. Moreover, the annual growth rate over the last decade was about 8%. [AARW01] According to the research of the Cambridge Systematics Inc, revenues from intermodal service accounted from about 18% of total railroad revenues in 1997. In addition, intermodal traffic and revenues are expected to increase by more than 50% in the next ten years as shown in Figure 1.5. [COIT99]



Source: Association of American Railroads.

Figure 1.4 U.S. Domestic Intermodal Rail Traffic

	Intermodal Traffic (Millions of Metric Tonnes)			Intermodal Revenue (Millions of $)		
Rail	**1996**	**2001**	**2006**	**1996**	**2001**	**2006**
Bulk	3	4	4	$ 108	$ 126	$ 159
General Freight	134	160	210	5,451	6,482	8,559
Total	137	164	214	$5,559	$6,608	$8,716

Source: American Trucking Associations, "U.S. Freight Transportation Forecast…to 2006," 1997.

Figure 1.5 Rail Intermodal Freight Forecast 1996-2006

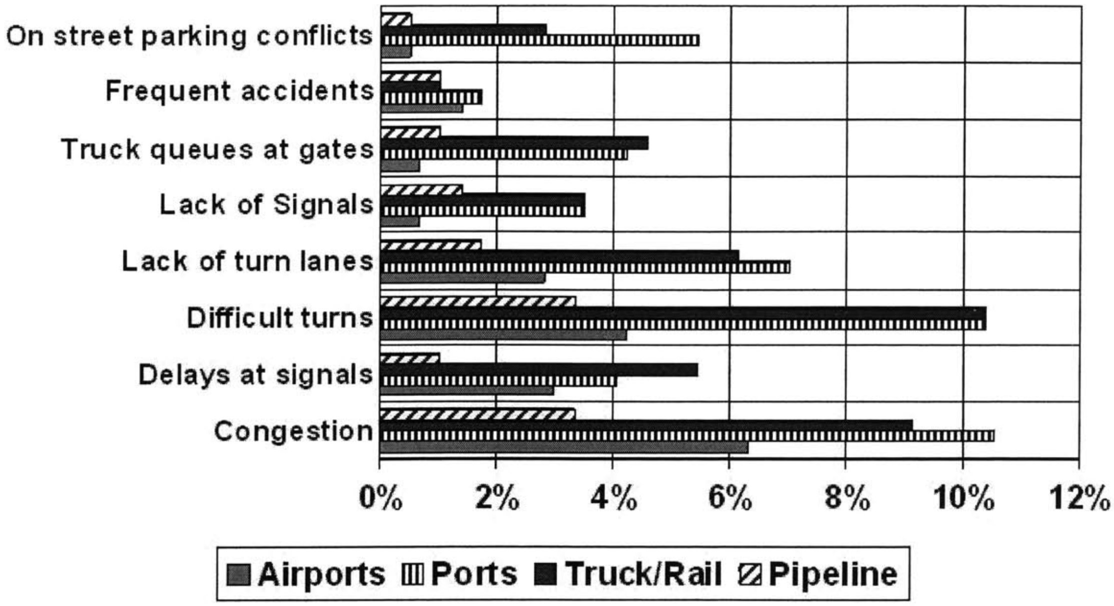
The volume of intermodal freight moved by truck has doubled over the last decade, and is expected to accelerate through the next decade. According to the statistics from Intermodal Association of North America in 1998, the domestic intermodal fleet of containers, trailers, and roadrailers grew by nearly 30% between 1992 and 1996 [TIN98]. The trucking industry could lose long-haul traffic to intermodal rail, but gain short-haul and regional drayage movements because of the overall increase in demand for intermodal freight service.

The number of intermodal containers moving through ports worldwide doubled over the last decade. Cambridge Systematics report states that the maritime containerized trade grew at a rate of 9.5% annually, and is expected to triple over the next two decades. “By 2010, experts predict that 90% of liner freight will be shipped in containers,” thus increase the possibility of using intermodal containers. [COIT99]

1.2.3 Intermodal Terminal Capacity Problem

We have described the basic definitions for intermodal freight transportation and illustrated the steady growth of intermodal freight demand. Next we will show the problem faced by intermodal terminals: expected poor performance of intermodal when capacity is reaching their limit, and resulted problems in the whole transportation network. We will also show why information technology, especially the integrated information system, may be a good choice over the next 5 to 10 years for improving the intermodal terminal performance.

Intermodal freight is transported all over the United States in significant volumes. In this great transportation network, intermodal terminals at times become bottlenecks and many problems emerge, as shown in Figure 1.6. When terminals with limited capacity cannot meet increasing demand, delays and congestion influence other components of the network. Because terminal delays account for roughly one-fourth of the time of delivering a container door-to-door [COIT99], advanced intermodal terminal technologies are a critical link between the global supply chain and the domestic transportation network.



Source: U.S. Department of Transportation, 2000 [NHSI00]

Figure 1.6 Traffic Operations and Safety Deficiencies

The growth of intermodal freight traffic and the pressure for improved performance have triggered major concerns about the capacity of ports and terminals, as well as the highways, marine and rail lines that serve them. Congestion and poor landside access are critical problems for ports and intermodal rail terminals. To solve this capacity problem, we have several alternative methods: expanding the infrastructure, managing the current facilities more efficiently, or applying a "just-in-time" strategy for the connection so to decrease the space required for storage.

New investments are planned to expand or refurbish ports, rationalize terminals, and improve intermodal connectors. But all of these projects are constrained by space, cost and environmental impacts. Most will take considerable time. Most rail terminals are located in densely developed urban areas. Additional space for container storage, railroad tracks, and truck roads is being purchased and developed, but slowly and usually at a very high cost. There are opportunities to develop new rail-truck terminals outside metropolitan areas, but these are also costly and have significant environmental impacts. For this reason, the capacity of terminals is almost fixed for the next decade. For the most part, the growth in intermodal freight traffic will be handled through existing terminals. Growth and capacity constraints are forcing the intermodal industry to look at redesigning operations and reengineering business practices to optimize the use of existing facilities in addition to making capital improvements.

Their location of intermodal terminals in urban area often prevents them from expanding the physical facilities at low cost and small environmental influence. However, urban location is an advantage for using information systems, because high-speed optical networks are available in metropolitan areas. Satellite receiver centers and wireless communication centers also focus on urban areas. Hence, much less investment would be required to build a communication network and central information system compared to what would be required in rural areas. This is one of the reasons that we highlight information technology as the major solution for resolving the capacity and performance problems of intermodal terminals.

Compared to infrastructure construction, information is much cheaper and easier to implement. Many available information technologies (IT) can be used to improve the terminal performance, including GPS, radio frequency AEI, and intelligent vehicles. [ITSO98] Applications of information technologies may improve facility productivity; they may reduce transaction delays by increasing lift productivity and reducing gate delays, terminal dwell times, and clearance times for inspections. Information technologies may also improve transit speed and reduce operating costs, thereby expanding the capacity for intermodal terminals and freight infrastructure.

However, most of the research on IT applications for intermodal terminals demonstrates some specific technology for a single mode or operation, e.g. AEI technology used in truck gate operation, without giving a clear view of the whole intermodal system, especially the communication among different transportation companies and their customers. Thus, more research is needed on system cooperation. An intermodal terminal is not an independent component in the transportation network; it influences and responds to other transportation components. For example, highway congestion may delay a drayage movement, so that a container misses a train and incurs a delay of a day in a domestic shipment. If the delay causes a container to miss a connection to a container ship, there could a delay of a week for an international movement. For this reason, the performance of the terminal is highly related to the performance of the highway network, the rail network, and carrier operations. The performance of the intermodal terminal can ultimately influence the whole supply chain.

To help resolve the capacity problem of intermodal terminals, we investigated terminal management, carrier operations and customer demand. We found the basic problem is information sharing. Because intermodal freight transportation is an activity that involves multiple transportation modes, companies and government agencies, cooperation is essential. In the traditional operation, each company has its own information system, and the data are accessible only by limited people outside the company. Limited information systems are currently available in most parts of the intermodal network, and some IT devices have been installed in trucks, trains, ships, and airplanes. Some private shipping companies have implemented shipment tracing systems to manage the flow of materials and products from the source to users. Some ports and terminals have implemented inventory and storage management systems. Some fleet managers are using asset location and management systems. Toll collection system enable the fast electronic payment through gates or entrances, etc. [COIT99] The problem we are facing is how to integrate these pieces of technologies within the intermodal terminal, add some components inside the terminal, and share all the valuable information in a seamless network.

Thus there is a need to design a comprehensive information system that uses advanced information technologies to improve the terminal management, transportation company information sharing and terminal customer service. And there is a need to investigate the technology capabilities of these technologies for the whole system, as well as their potential costs and benefits.

1.3 Research Approach

First, we will determine system requirements for an integrated information system for intermodal terminals. To do this, we will review the types of intermodal terminals, terminal operation procedures, and terminal equipment and facilities. In addition, we will investigate the internal and external factors that can influence intermodal terminal performance, so that we can explore the information technologies and systems that may change these factors and improve the terminal performance.

Second, we will survey the available information technologies and information systems, in order to identify technologies that can be used in an integrated information system.

Based on the above information, we will propose an Intermodal Terminal Management Information System (ITMIS) that integrates many kinds of useful information within intermodal terminals and shares the information across the whole intermodal network. Furthermore, we will demonstrate how to incorporate positioning, communications and other information technologies to ensure the good performance of ITMIS.

Next, we will review the information technology applications in other transportation areas and try to find their costs and benefits for network components, transportation modes, or information systems. Finally, we will use previous IT research and queuing models to estimate costs and analyze potential benefits of the proposed ITMIS, and we will investigate some possible applications for improving the cooperation among terminals and among terminals and carriers.

1.4 Thesis Outline

This thesis demonstrates a comprehensive architecture for an Intermodal Terminal Management Information System (ITMIS), and shows the information technologies applied to ensure the operation of this system. It then addresses costs and benefits using queuing theory and some simulation models developed for terminal performance management and evaluation.

Chapter 1 introduces intermodal transportation and the growth of intermodal freight demand. To illustrate the terminal capacity problem, it describes how increasing intermodal freight demand is causing terminals to reach capacity limits based on current facility and management. The objective of research is to show how sharing information within the intermodal network can help terminal managers deal with capacity and performance problems.

Chapter 2 investigates the types of intermodal terminals, terminal operation procedures, and facilities and equipment in the terminals, so that we can determine system requirements for an integrated information system for intermodal terminals. This chapter also investigates the internal and external factors that can influence terminal performance, so that we can understand how to design an ITMIS and use information technology to change these factors and, furthermore, improve the terminal performance.

Because knowing capabilities of information technologies is an important point in designing an integrated terminal management information system, chapter 3 investigates technologies available for cargo and vehicle tracking, communication, and terminal control. To design an integrated information system at intermodal terminals, we will integrate information from the other components in the intermodal network, in order to save investment in new infrastructure and equipment. Chapter 3 also scans current or proposed information systems for highway, marine and rail networks.

Chapter 4 proposes the architecture of the Intermodal Terminal Management Information System (ITMIS), the data models of central database, and the functions of several modules—data entry, reservation system, query and terminal control modules. This chapter selects information technologies to ensure that the ITMIS can handle the anticipated data flows and processing requirements.

Next, chapter 5 shows the potential improvements from ITMIS compared to current terminal information systems. First, estimates of system cost are based on the configuration of servers, workstations, LAN, and other elements of the proposed ITMIS. Second, queuing theory and simulation models are used to calculate potential terminal capacity improvements from ITMIS. Finally, several examples illustrate the potential benefits that can be obtained by sharing information among regional terminals.

Chapter 6 summarizes the research results and the implications for intermodal terminal management. It also makes recommendations for further research concerning information systems for intermodal terminals management.

Chapter 2 Intermodal Freight Terminals

In this chapter, I investigate intermodal terminal types, terminal operation procedures, as well as facilities and equipment in intermodal terminals. This background information is needed to make the data model for the central database and to set the system requirements for the integrated information system for intermodal terminals. I also talk about the internal and external factors that can influence the terminal performance, so that we can see how to change these factors with an integrated information system and further improve terminal performance.

2.1 Intermodal Freight Terminal Types

The intermodal terminals database is a database for U.S. intermodal freight terminals, and it is being developed and maintained by the Bureau of Transportation Statistics. Middendorfa defined a freight terminal in the description report of the intermodal terminal database, "A freight terminal is an integrated set of facilities where cargo is loaded onto or unloaded from a particular mode of transportation. An intermodal freight terminal is a special kind of freight terminal. It is a place where two or more modes of transportation meet to interchange fright, either directly or through intermediate storage." [ITD01] At intermodal terminals, the cargo may be consolidated with other inbound cargo, separated into smaller outbound shipments, or directly transferred between two modes.

Intermodal freight terminals differ in size, complexity, and functionality. Some terminals cover many acres of land with multiple buildings, storage spaces, and gates; other terminals include very little infrastructure or sophisticated equipment. As of October 1997, there are 2865 intermodal freight terminals and 9036 intermodal connections in the intermodal terminals database. [ITD01] According to the description of the database, it is only partially completed yet and a full database could contain double number of records. An US DOT report in year 2000 shows that there are 517 freight-only terminals connected to the National Highway System, which includes 253 ports (ocean and river), 203 truck/rail, and 61 pipeline/truck terminals. In addition to these freight-only terminals, there are 99 major freight airports, which handle both passenger and freight. [NHSI00]

Intermodal terminals have a wide variety of types: trailer-on-flatcar/container-on-flatcar (TOFC/COFC), auto terminals, truck-rail bulk transloading facilities, truck-rail reload facilities, liquid bulk terminals, grain terminals, and waterway intermodal terminals.

TOFC/COFC terminals are places where either containers or trailers are transferred between truck carriers and railroads. Containers and trailers may be directly transferred to another mode, or may stay on the storage area for a short period then be loaded onto and hauled away by another mode. The intermodal terminal database indicates that the number of TOFC/COFC facilities in the United Sates has dwindled from 2000 in the 1970s to around 235 in December 1996. The smallest terminal covered only one or two acres and had less than 25 parking spots, while the largest terminal spanned over 250 acres and provided over 1000 parking spots. About half of these terminals covered less than 25 to 30 acres and had less than 400 parking spots. The average size of a TOFC/COFC facility was about 40 to 45 acres with approximately 700 parking spots. Almost all terminals operated some type of lift equipment, including 95 terminals with at least one overhead crane. At least 90 TOFC/COFC terminals had an annual lift capacity of at least 100,000, and 28 terminals had the capability of handling at least 250,000 trailers and containers annually. The four largest facilities in the United States had annual lift capacities of 700,000 to 900,000 trailers and containers for each terminal. [ITD01]

Truck-rail bulk transloading facilities are terminals connecting highways and railroads, handling non-containerized dry bulk cargo. They are scattered and may be found virtually anywhere there is enough siding space as well as space for trucks and equipment. As shown in MBT Directory of Bulk Truck Transfer Facilities in 1996, their size or capacity may be as small as two and as large as 450 railcar spots. The average size appears to be around 60 car spots, but half of the truck-rail bulk transloading facilities have less than 35 to 40 spots [MBTD96].

Truck-rail reload facilities are open yards, warehouses and distribution centers where break-bulk cargo is transferred between truck carriers and railroads. The cargo may be directly transferred between modes using forklifts, cranes, or other suitable equipment, or it may be placed in a storage area for a short period before being loaded and hauled away by another mode. As stated in intermodal terminal database, three types of reload facility can be identified. [ITD01] The first one is an open yard generally used for transferring logs and pulpwood. The second type is a warehouse or distribution center whose primary function is to transfer a specific type of commodity between truck and rail. The third type is a regular public warehouse or distribution center with multiple functions. Many warehouses and distribution centers are being designed or modified to facilitate truck-rail transfer. [BCTB96]

Waterway Intermodal Terminals include terminals to transfer cargo between highway or rail and water modes of transportation. They are along the Atlantic, Pacific, and Gulf coasts, the Great Lakes, inland rivers, lakes, and canals. "The size, layout, and other physical characteristics of waterway intermodal terminals vary considerably." [ITD01] A waterway intermodal terminal generally has one or more docks, some cargo storage area, cargo handling equipment, and spots for trucks and/or railcars. A water intermodal terminal's storage facilities and equipment are determined by the kinds and volume of cargo that go through the terminal. [MPA01]

In this paper, I will mainly discuss the information system for TOFC/COFC intermodal terminals, not only because it is the major concern for rail intermodal companies, but also because concentrating on one type of the terminal would be clearer to state the system requirement, system design, and cost/benefit analysis. For terminals other than TOFC/COFC, there may be some different system requirements to handle different cargo type. However, the design of information systems for other types of intermodal terminals would be similar to the system for TOFC/COFC terminals, and the basic idea for information sharing among the intermodal network is the same, so that only small modifications need to be made for the central database of the system.

2.2 Terminal Operations

To clarify the requirement of terminal information system, a review of the various steps in the intermodal process and activities that occur within an intermodal freight terminal would be helpful. There are four general processes for terminal operation: gate operation, pickup or dropoff of trailers and containers, movement inside the terminal, and train loading/unloading. Here we use a truck-rail intermodal freight terminal as an example to illustrate terminal operations and corresponding information flow through these processes and activities.

1) At the beginning, the customer issues a purchase order to a shipper, and gets an acknowledgement from the shipper. Then the shipper would book, confirm, and schedule motor and rail carriers. The motor carrier would schedule and route drivers for the shipments. Next, the shipper provides shipment manifest to the driver. Given an order, the intermodal process begins when the railroad dispatches a local trucker or a drayman to move an empty trailer or container from the intermodal terminal to the origin point.

2) The driver notifies the shipper of arrival, and presents delivery order, bill of landing. The shipper verifies container/trailer and driver appointment. Cargo is loaded in a trailer or container at the point of origin. The trailer or container is hauled by the tractor from the point of origin to a transfer facility--origin rail intermodal terminal. In the transit, the driver would report the status of vehicle and cargo to the motor carrier if a local trucker moves the cargo, or the driver would report status to the terminal if a drayman moves the cargo. At the same time, the documentation of cargo is also in transit either physically or electronically.

3) The motor carrier books appointment at rail terminal, and the terminal confirms the appointment. The motor carrier notifies the railroad of arrival at the terminal gate. The trailer or container arrives at the terminal, and is inspected at the terminal entrance gate. After administrative information is confirmed (the terminal verifies container/trailer

appointment and driver identity, then issues pass and clears for entrance), the trailer or container is usually parked at the terminal storage area until the appropriate time for loading. “The total time a trailer or container spends at the origin terminal prior to being loaded on a rail car is referred to as the origin terminal dwell time”. [NITS95] The rail terminal produces terminal plan and assigns unloading point and handling equipment. The terminal issues delivery receipt to motor carrier after container/trailer is dropped off, and clears truck for departure.

4) The trailer or container is hauled from its storage location to a spot alongside the loading track by terminal hostling or lift equipment. Sometime the trailer or container is not stored but moved directly to a spot alongside a rail car, and the operation is referred to as advanced staging or “live lifting”. In order to put the trailer or container on a scheduled intermodal train, the trailer or container must have arrived at the terminal before a published “cutoff” time. [NITS95]

5) The rail terminal identifies the container/trailer on terminal plan and notifies railroad of loading point, and forwards delivery receipt to the railroad. The trailers and containers are loaded onto a rail car either singly or in a double stack. The loaded rail car is moved from the loading track to a storage track at or near the origin terminal or at a supporting rail yard. The delivery order, manifest, and bill of lading are also forwarded to the railroad.

6) The trailer or container is moved in trains to another terminal. The origin terminal notifies the destination terminal of the estimated trailer or container arrival time. In some cases, the trailer or container may be unloaded from its original rail car at one facility and drayed to a second intermodal rail terminal where it is rehandled.

7) The loaded rail car arrives in the destination intermodal rail terminal, and is put on a storage track until the appropriate time when it is switched onto an unloading track.

8) The trailer or container is unloaded at the destination terminal by lift equipment and, usually, moved to a storage location. The trailer or container is stored until the appropriate time for pickup that is usually after a scheduled time referred to as the "release time". [NITS95] The total time a trailer or container spends at the destination terminal after being unloaded from a rail car is referred to as the destination terminal "dwell time". Sometime the trucker or drayman would pickup the trailer or container just after it is unloaded, which is called "just-in-time" pickup, and the dwell time is close to zero.

9) The trailer or container is removed from storage by a local trucker or drayman, inspected at the gate and moved to the final destination point. The owner of the cargo unloads the trailer or container and contacts the railroad to pick up the empty trailer or container.

10) The railroad dispatches a drayman to move the empty trailer or container to another customer or return it to the intermodal terminal.

The above example showed that functions provided by an intermodal truck-rail terminal include activities of drayage (steps 1, 2, 10), gate processing and gate-storage/storage-gate transfer (steps 3, 9), hostling inside terminal (step 4), track switching (step 7), train loading/unloading (steps 5, 8), and truck pickup/dropoff (step 9), etc. These activities are performed by rail companies, truck companies, terminals, and drayage companies of the intermodal system, and the shippers also involved in the activities, so that the integrated terminal information system need to supply different query or control modules for all kinds of the above companies. A more detailed description of intermodal terminal operation steps could be found in the US DOT report "National ITS/Intermodal Freight Program Requirements", which include truck-air, truck-water and truck-rail intermodal cargo movements and information flow [NITS99].

2.3 Terminal Facilities and Equipment

To ensure good terminal operation as described in the last section, there are different kinds of terminal facilities and equipment for each process activity. This information are important to be included in the system because the inventory of terminal resources can be not only helpful for local terminal management, but also helpful for other terminals or transportation companies who would like to use these resources.

For activities of inbound or outbound cargo or vehicle inspection, there are terminal gates (there may be two phases of gates: pre-gate to pre-sort the vehicles and gate for inspections; sometime the direction of gate inspection for inbound/outbound may change once or twice in one day) and waiting lanes (normally part of the lanes are specified for trucks without trailers to directly go through the gate because it does not need inspection). The gate operation involves security check, equipment interchange, liability transfer, and cargo information processing. Gate capacity is determined by the entrance queuing space for trucks to go through the gate and enter the terminals, and the throughput rate of the gate. Thus in the terminal management information system, we need to include the information of the number of gates, specified vehicle type for each gate, number of lanes, direction and length for each lane.

For track switching of cars, the information of the number of locomotives, the number of tracks, length and other characteristics of each track, and track status (available / reserved / busy) are needed to be included in the information system. This is related to track capacity, which is determined not only by the layout of the terminal and length of the tracks but also by the frequency with which the railroad switches flatcars on and off terminal tracks.

Storage space is another important terminal resource. It can be divided into different areas for different types of cargo or equipment. Storage capacity is determined by the size of dedicated storage areas for containers, trailers, and chassis. It is a dynamic, complex function that is affected by how a facility is operated and by the diverse space needs of intermodal equipment on terminal property. The related information may include the space ID, location, status, current cargo or equipment in the space, etc. If the cargo is stacked in one space, a level ID should be included in the space ID to differentiate the top, middle, bottom or even more levels. (There may be three to four empty containers stacked together.)

In addition to these fixed resources, there is some equipment in the intermodal terminals. For train loading or unloading, lift equipment is needed. Lift capacity is determined by not only the time available to unload and load flatcars, but also the type, number, and mix of machines assigned to load and unload intermodal equipment, and the rate at which such equipment is delivered to and removed from trackside. Thus the information system needs to include the number, type, capability, status, location and other characteristics of lift equipment.

For cargo transfers between the gate and storage places, hostlers' information should be included in the information system. Moreover, we need the type, capability, location, and status of the container, chassis and trailer information for drayage or storage.

Crews are very important terminal resources, and there are specific crews for various activities or processes in the terminal. For example, there are switch crews to operate car switching, crews to operate cranes, hostlers to move cargo between storage areas and the gate or between tracks and storage areas, and draymen to move trailers from the terminal to truck companies. The information of crew ID, their skills to handle special activity, status, location, schedule and cost should be included in the terminal information system as well.

Except for these terminal resources, there are carriers involved in the activities in intermodal terminals: trucks, trains, ships, etc. If their location, speed, arrival or departure times, and other characteristics are included in the information system, we will have better estimation or forecasting for terminal resource demand, so that better utilization of the terminal facility and equipment would be achieved.

2.4 Factors Influencing Terminal Performance

The normal measures for intermodal freight transportation used by government and companies are: accessibility of intermodal facilities, availability of intermodal facilities, cost and economic efficiency, safe intermodal choices, connectivity between modes, and time. [PTUS00] Some research on terminal performance measures has begun, but much more is needed before a standard set of terminal cost and performance indicators can be specified. Most likely different sets of indicators will be needed for different types of terminals. No single measure or indicator of terminal performance has been widely accepted, and the terminal performance can be different from different perspectives. The transfer time, operating cost, storage ability, terminal throughput, congestion and delays, securities, as well as energy usage are all relevant to the terminal performance. At any given terminal, terminal performance is a variable, and it changes over time in response to many interacting factors. Some of these factors are internal, others are external. Knowing these factors can be helpful to recognize the useful technology to improve terminal performance by changing one or more factors, and it is also helpful to understand how terminals can benefit from the new technology and information system.

There are several internal factors influencing terminal performance. The first internal factor is terminal capacity, or the amount of freight of a certain type that the terminal is potentially capable of handling over a specified interval of time under the most advantageous conditions. There are four broad processes that might influence terminal capacity: 1) gate operations, 2) lifting operations, 3) storage for trailers and containers, and 4) track spots for rail cars. The capacity of gate operations is a function of the number of lanes, the hours of operation, and the average processing rate. The lifting capacity is a function of the number of cranes or other lift equipment, the hours of operation, and the average time per lift. The storage capacity could be estimated as the number of parking spaces multiplied by a stacking factor and the number of containers/trailers per week per parking space. The track capacity is limited by the number of car spots multiplied by the number of containers or trailers per car multiplied by the number of times the track is switched per week. Terminal capacity is an important factor since we have known from chapter 1 that the intermodal freight demand is increasing steadily, the terminals are usually located in the urban area, and the infrastructure construction is time consuming and expensive, so that the intermodal terminals are expected to experience capacity problems in the near future. Physical layout of the terminal can affect terminal capacity and determine how smoothly or quickly cargo can go through the terminal. Available equipment can also affect terminal capacity and determine how expeditiously cargo can be unloaded, transferred, stacked, stored, reclaimed, and reloaded.

The second internal factor is the terminal operating procedures and labor work rules as well as labor availability, experience, and disposition, which may either facilitate or hamper intermodal transfers. The optimal schedules can be achieved by using real time information and automatic management software.

The third internal factor is terminal utilization at any given moment or the percentage of terminal capacity being utilized. Resource utilization can be measured as the ratio of the time that a resource is in use to the time that the resource is available for use. For an intermodal terminal, the major resources include labor, land, lift equipment, and fixed facilities. The number of gate lanes and cranes can be adjusted as the workload varies. Because the terminal utilization is based on available resources and their capabilities to handle different types of cargo, the reservation system and real time resource inventories could help terminal managers to improve resource allocation by optimization software, and to make demand adjustment by pricing strategy, therefore achieve higher terminal utilization.

Intermodal terminal is not an independent component in the transportation network; it influences and responds to other transportation components. For example, the congestion in highway may cause delays in a drayage movement, so that the container may miss a train and cause a delay of a day in a domestic shipment, or the container may miss an international ship and cause a delay of a week in an international movement. For this reason, the performance of the terminal is highly related to the performance of the highway network, the rail network, and ocean carriers. The performance of the intermodal terminal would influence the whole supply chain as well. Thus we need to consider some external factors that can affect terminal costs and performance.

The first external factor is delays, breakdowns, or disruptions on other parts of the transportation system. These problems are due to heavy traffic, shortages of railcars or other modal equipment, shortages of truck drivers or railroad crews, accidents, bad weather, labor strikes, or natural disasters, etc. An integrated information system would be helpful to alarm the terminal about these incidents or problems happened in other parts of the intermodal network, so that terminal managers can modify terminal operation schedules according to the changes in advance.

The second external factor is the extent of coordination between modes of transportation, which determines how often and how long a freight shipment may have to wait at a terminal before being shipped out. This is a very important factor since the connection between different modes of transportation is the key function of intermodal terminals.

We have discussed the factors that can influence the terminal performance. Now we will see if information systems and technologies are potential choices to change some of these factors. Because infrastructure construction is expensive and time consuming, and information technology is attractive for improving terminal performance in a relatively shorter time, information technology has a revolutionary impact on intermodal freight transportation. It provides tools for sharper and more focused operations, and for strategic partnerships and new supply chain relationships. The available IT applications can be used to influence either the internal or external factors of terminal performance. From the view of supply chain management, global transportation and logistics are rapidly being transformed by using information technology to identify and monitor cargo and equipment in real-time virtually anywhere in the world. These technologies have been applied both to line haul activities and to intermodal transfer operations. In the next chapter, we will discuss the capabilities of information technologies and see how they can be used in intermodal terminal management information system.

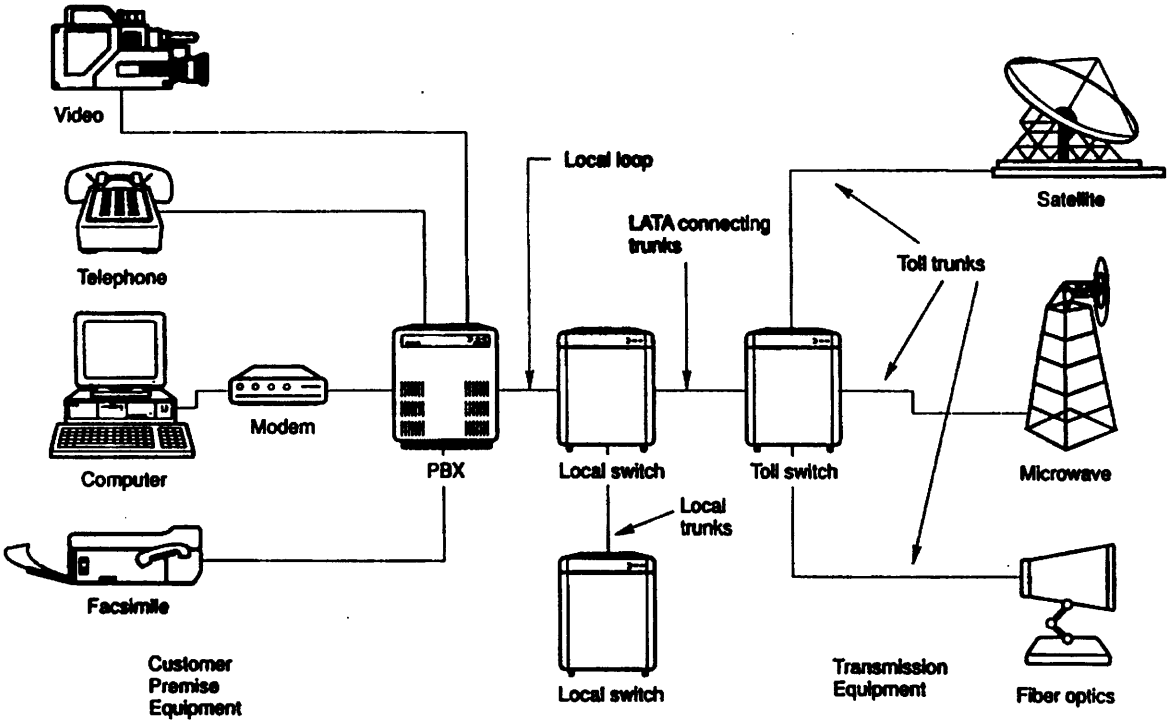
Chapter 3 Investigating Technologies for Intermodal Terminal Management

In this chapter, I will discuss the advantages and disadvantages, characteristics and capabilities of several information technologies that can possibly be used in intermodal terminals and help to build an integrated information system: satellite communication, wireless communication, video system, automated guided vehicles, data exchange protocols, and terminal control software. I will also discuss what information technology can be used for integrated information systems, based on their capabilities. The technologies described in this chapter could possibly be used to support the data entry, information transmission, and information sharing for the intermodal terminal management information system (ITMIS) that will be proposed in the next chapter.

3.1 Communication Technologies

By using wireless or wireline technology, we can broadcast voice, data and video on a gigantic wide area network, or make point-to-point transmission. Usually, voice is carried at up to 64 Kb/s, data is carried at various rates, and video is carried at 5Kb/s to 10Mb/s, which depends on the quality requirement and compression standard. Figure 3.1 shows the major classes of telecom equipment. From the customers' view, video camera, telephone, fax machine and computers are equipment that they need to invest on. The communication agencies provide different communication services to customers by using satellite, microwave or fiber optics.

The major transmission systems include: lightwave (applications are Local Area Networks, long-haul transmission, fibre channel for high-speed computer communication, etc.), microwave radio (applications are wireless local loop, bypass T1 circuits, interconnecting LAN, local data communication network, etc.), satellite (applications are GPS, direct broadcast satellite, etc.), and wireless system (mobile radio, cellular phone and Personal Communication System--PCS).



Source: The Irwin Handbook of Telecommunications, 2000

Figure 3.1 Major Classes of Telecom Equipment

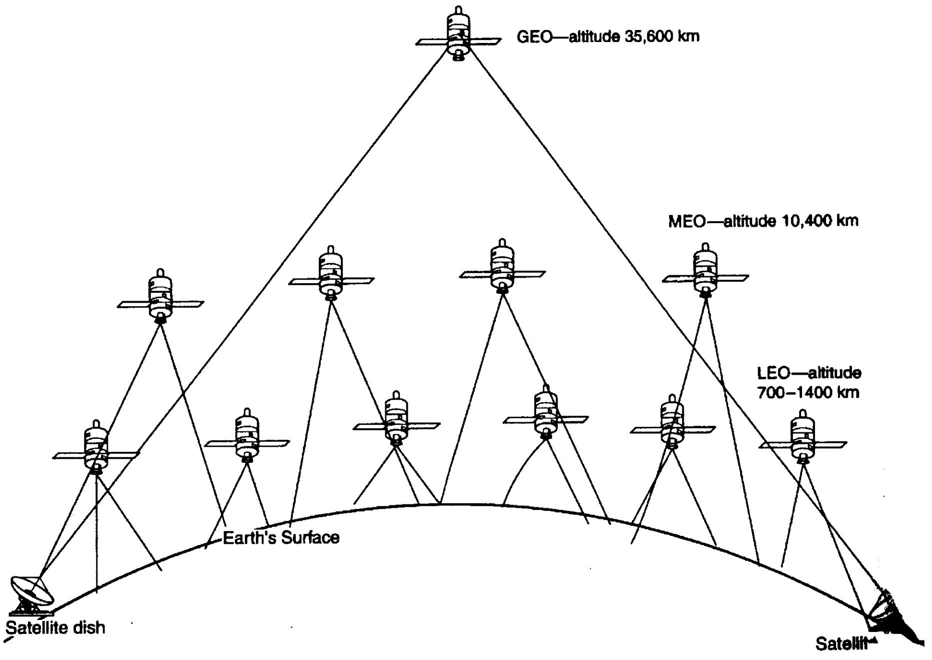
Technology	Bandwidth	Error Rate	Distance
Fiber	1-100Gb/s	10^{-14}	Any
Microwave	45 Mb/s	10^{-6}	Short, bypass
Cellular	19.2 kb/s	10^{-6}	5 miles from base
Satellite	9.6 kb-1Mb/s	10^{-6}	1000s of miles
CATV	1 Mb/s	10^{-10}	5 miles from base
DSL	<1 Mb/s	10^{-10}	3 miles from CO
ISDN	144kb-1.5Mb/s	10^{-10}	3 miles from CO

Source: MIT Class 1.264 Lecture Notes, Sep 2001

Table 3.1 Telecom Technologies for Data Transmission

Based on the different features of bandwidth, transmission error, and distance coverage shown in Table 3.1, we can select appropriate technologies for different components of intermodal terminal management. Because vehicles are always moving, it is hard to apply fiber technology to communications involved with them. Considering the distance issue, wireless communication and satellite communication technologies seem to be the best choice for vehicle tracking and positioning. The distance of microwave communication is short so that it is suitable for bypass in terminal gates operation or other information scanning operation. Fiber optics is the dominant technology for data transmission between fixed users. Because of its high bandwidth, low error rate and big coverage area, it is an excellent choice to share information between terminals and other transportation companies. To monitor the terminal operation management and improve regional terminal cooperation, CCTV can be used inside terminals and between adjacent terminals.

3.1.1 Satellite Communications



Source: The Irwin Handbook of Telecommunications, 2000

Figure 3.2 Communication Satellites Orbits

There are three orbit classes: geosynchronous (GEO) satellites, which orbit the equator at an altitude of around 36,000km; medium earth orbit (MEO) satellites, which orbit the earth at around 10,000 km and offer voice, data, paging and fax services over their network; low earth orbit (LEO) satellites, which orbit the earth at an altitude of 700 to 1400 km. The lower the orbit, the more satellites needed, but the lesser the delay.

Satellites have many advantages over terrestrial communications. Firstly, costs of satellite circuits are independent of distance as long as it is within the coverage range of the satellite, and satellites can reach wide areas and serve many users simultaneously. The satellite sends signals to end users directly, so there is no need to use the expensive local telephone facilities. Satellites can also provide high-quality communications service to areas that are difficult or impossible to be served by terrestrial communications, because a satellite's coverage is independent of terrain and other obstacles. Additionally, satellite communications provide larger amounts of bandwidth than terrestrial communications, making high-speed data transmission possible, and earth stations can verify the data-transmission accuracy.

However, satellite communication has its own limitations. The delay from earth station to GEO satellite and back is about ¼ second, which is higher than the delay of terrestrial circuits. Sometimes, path loss can be up to 200dB from earth to satellite, and it is affected by weather conditions, particularly at higher microwave frequencies, thus the lack of frequencies is a disadvantage of satellite communication. Multiple hops are required when the distance between earth stations exceeds the satellite's footprint, but such satellite connections impose a delay that affects the quality of voice communications and should be avoided.

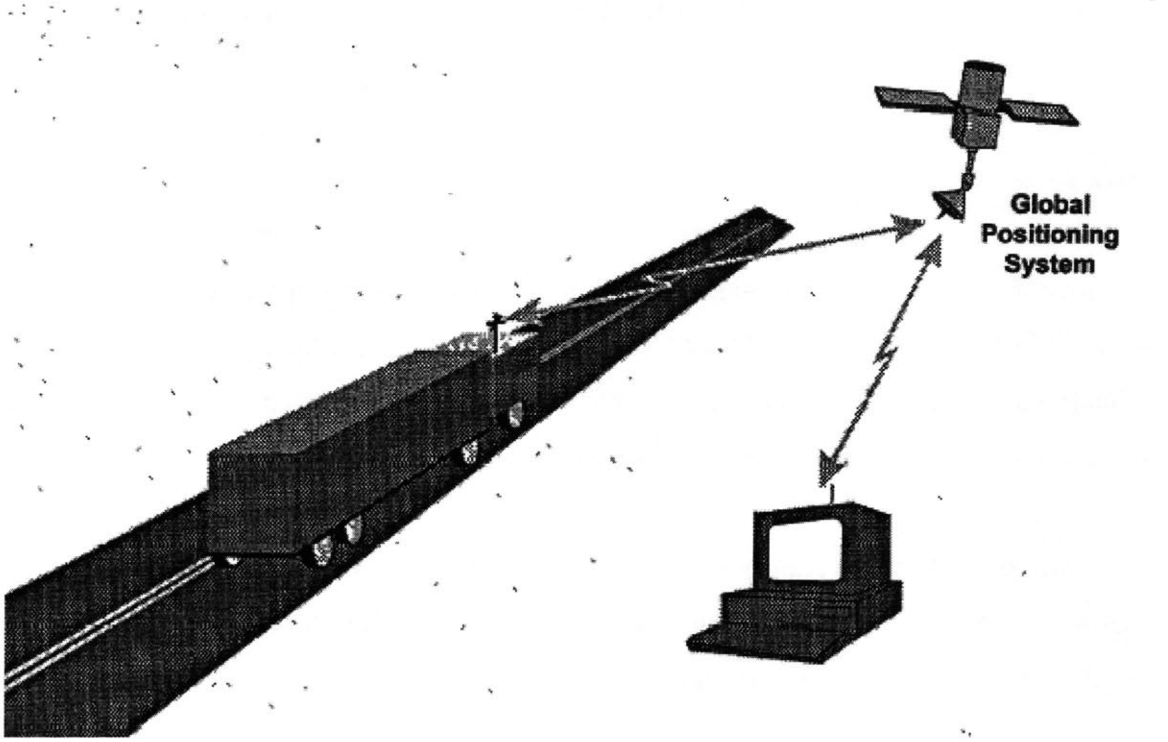
There are many different types of satellite services. For example, Iridium used 66 LEO satellites to provide voice, paging, and narrowband data service worldwide. It enables callers to stay in telephone contact virtually anywhere in the world, but the service is expensive--$3 per minute. Voice is digitized and compressed to 2.4 ~ 4.8 kb/s. The maximum speed of data transmission is 2.4 kb/s per link. [ISS01]

International Maritime Satellite Service (INMARSAT) has a network of 17 coastal earth stations and is sponsored by the International Maritime Organization. INMARSAT type accepts and regulates shipboard equipment, and it also "provides the same kinds of communications services for ships at sea that land stations can access through satellite or terrestrial circuits: voice, video and facsimile". [IMO01] Other services that do not generally apply to land stations can also be accessed: ship locations can be monitored precisely through polling equipment; distress calls can be received and rebroadcast to ships in the vicinity but out of radio range; and broadcasts, such as storm warnings, can be made to all ships at sea.

Very Small Aperture Terminal (VSAT) network is star-connected with a hub at the center. As stated in VSAT forum website, "VSATs are used for a wide variety of telecommunications applications, including corporate networks, rural telecoms, distance learning, telemedicine, disaster recovery, ship-board communications, transportable fly-away systems, and much more. VSATs are becoming increasingly popular, because they are a single, flexible communications platform that can be installed quickly and cost effectively to provide telecoms solutions for consumers, governments and corporations. They have been in use for more than 10 years and, with more than 500,000 systems operating in more than 120 countries, VSATs are a mature and proven technology." [VSAT01] The primary application for VSAT is data transmission, although it also can carry voice and video. The data is carried at 9.6kb/s ~ 56kb/s, and some systems carry a full or fractional T1 or E1. VSAT supports multiple locations. As the number of remote sites increases, VSAT becomes more attractive.

Global Positioning System (GPS)

Trimble defines Global Positioning System (GPS) as "a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations". [TRIM01] GPS includes three segments: space segment, control segment, and user segment. The Space Segment of the system consists of the MEO satellites. These satellites send signals from space while orbiting the earth, and provide users that are almost everywhere on the earth with five to eight visible satellites. The control segment consists of a system of tracking stations around the world. These monitor stations measure signals from the satellites, and incorporate them into orbital models. The models compute precise orbital data and clock corrections for each satellite. The Master Control Station uploads orbital and clock data to the satellites, and then the satellites send subsets of the orbital ephemeris data to GPS receivers. The GPS user segment consists of GPS receivers and the user community. GPS receivers convert satellite signals into position, velocity, and time estimates, and then these data can be used for navigation, positioning, time dissemination, and other research. Nowadays, GPS receivers have been miniaturized to just a few integrated circuits, so that the technology is becoming economical.



Source: Federal Highway Administration, 1996 [ITSJ96]

Figure 3.3 GPS Technology

The GPS navigation message consists of time-tagged data bits marking the time of transmission of each sub frame at the time they are transmitted by the satellites. A data bit frame consists of 1500 bits divided into five 300-bit sub frames. A data frame is transmitted every thirty seconds. Three six-second sub frames contain orbital and clock data. Satellite Clock corrections are sent in sub frame one and precise satellite orbital data sets (ephemeris data parameters) for the transmitting satellite are sent in sub frames two and three. Sub frames four and five are used to transmit different pages of system data. An entire set of twenty-five frames (125 sub frames) makes up the complete navigation message that is sent over a 12.5 minutes period. [GPSO94]

According to the Federal Radio Navigation Plan, civil users worldwide can use the standard positioning service (SPS) without charge or restrictions. SPS is predicted to have 100 meters horizontal accuracy, 156 meters vertical accuracy, and 340 nanoseconds time accuracy. Authorized users with cryptographic equipment and keys and specially equipped receivers use the precise positioning system (PPS). PPS is predicted to have 22 meters horizontal accuracy, 27.7 meters vertical accuracy, and 200 nanoseconds time (UTC) accuracy. [GPSO94]

Differential GPS (DGPS)

Because GPS is not very accurate, and there are common errors when receivers are close to each other, people use Differential GPS for navigation or positioning with higher requirement instead of GPS. DGPS can yield good measurements to a couple of meters in moving applications and even better in stationary situations based on SPS signals.

GPS receivers use timing signals from at least four satellites to establish a position. Since each of the timing signals that go into a position calculation has some error, the calculation is going to be a compounding of those errors. The satellites are so far out in space that the little distances we travel here on the earth are insignificant. So if two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have traveled through virtually the same distance, and so will have virtually the same errors.

The idea behind the differential GPS is to correct bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, has been very accurately surveyed and is kept in a position. This reference station receives the same GPS signals as the moving receiver, and computes corrections for each satellite signal. Instead of using timing signals to calculate its position, it uses its known position to calculate timing. It figures out what the travel time of the GPS signals should be, and compares it with what they actually are. The difference is an "error correction" factor. The receiver then transmits this error correction information to moving receivers so that they can use it to correct their measurements. [GPSO94]

Trimble Navigation states, “The United States Coast Guard and other international agencies are establishing reference stations all over the place, especially around popular harbors and waterways.” “Anyone in the area can receive these corrections and radically improve the accuracy of their GPS measurements.” [TRIM01] Most ships already have radios capable of tuning the direction finding beacons, so adding DGPS will be quite easy. Many new GPS receivers are being designed to accept corrections, and some are even equipped with built-in radio receivers.

Inverted DGPS is a permutation of DGPS. With an inverted DGPS system, the vehicles would be equipped with standard GPS receivers and a transmitter and would transmit their standard GPS positions back to the tracking office. Then at the tracking office the corrections would be applied to the received positions. DGPS gives very accurate positions with costs of one reference station, a computer and a lot of standard GPS receivers. [GPSO94]

3.1.2 Wireless Communication

The demand for cellular service grew rapidly, so that carriers need additional frequencies and are shifting to digital cellular. Green said in year 2000 “Over the next several years, digital cellular with its greater channel capacity will replace analog.” [TIHT00] There are different multiplexing methods that are in use throughout the world. Time division multiple access (TDMA) is the first digital cellular method to reach users. Code division multiple access (CDMA) is adopted by several North American carriers. In much of the rest of the world, global system for mobile communications (GSM) is the dominant digital cellular scheme. PCS-1900 is the North American version of GSM, and is used for PCS. It is not, however, completely compatible with European GSM, making it impossible to use the same phone in all parts of the world.

The following two graphs are from Green's book "The Irwin Handbook of Telecommunications" [TIHT00], and they describe the characteristics and advantages of PCS compared to cellular:

> "Personal Communications system (PCS) promises that the telephone number areas associated with people, not places, and you can use the service or be reached anywhere or any time. PCS is improving lifestyle through a combination of easy portability and random mobility. Easy portability means the telephone instrument is a small size that fits the user comfortably. Random mobility means that subscribers can roam and use their personalized services wherever they are. Except for dead spots, users can be reached easily without caller or called party being concerned about special check-in procedures as cellular sometimes requires. A nationwide signaling network is needed to identify PCS roamers and to inform the local carrier of the subscriber's personalized services. Smartcards may enable subscribers to use any telephone on the network while keeping the system informed of their identity and preferences.
>
> PCS is similar in many ways to cellular, but with several notable exceptions: PCS omitted the analog phase—it is a digital service from the outset; Its frequency range is higher—in the 1900 MHz band; The PCS spectrum is divided into licensed and unlicensed portions, which enables private wireless users to shift to an adjacent PCS frequency when they roam outside the bounds of the unlicensed system; The frequency spectrum for PCS in the Untied States was auctioned off and divided into multiple segments to avoid some of the monopolistic characteristics of cellular. "

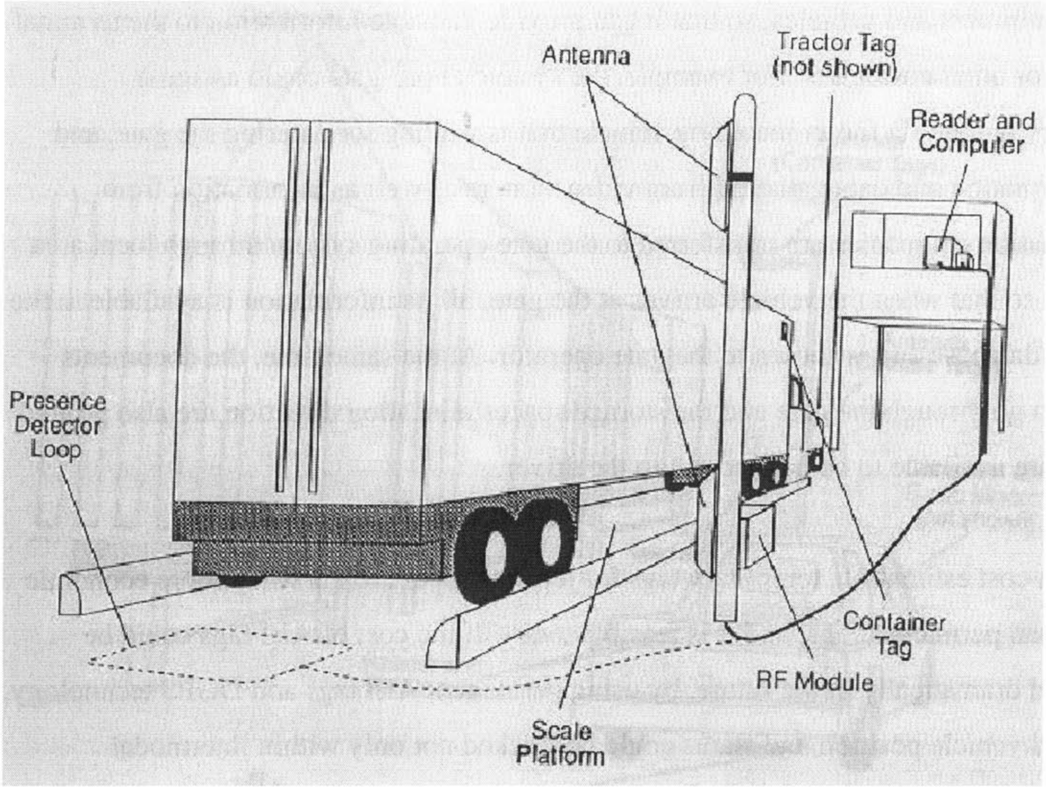
The evaluation criteria for cellular mobile telephone include reliability, coverage, ease of roaming, blockage, and security. The coverage area is one of the primary considerations most users review in evaluation. Every cellular operator provides a home area in which normal cellular rates apply. Roaming is the ability of a mobile unit to move outside its normal service area. The blockage rate is how often the users encounter a reorder signal in attempting to place calls with the carrier. CDMA is more secure than TDMA, and GSM uses a unit identification protocol that is inherently more secure from fraud; the mobile unit receives an identification number from a pool just for the duration of the session.

Paging is a radio application that is less sophisticated and less costly than cellular radio, and it is growing fast. One type of radio paging offers dial access from a wireline telephone to a receiver. Digital pagers allow the caller to send a callback number or numeric message to a digital receiver. Alphanumeric paging can send a text message, so that reduce the number of cellular phone messages at lower cost. The answerback paging can let the recipient answer by pressing a button on the pager and the pager sends an acknowledgment to the sender. Some pagers enable the user to send messages to other one-way and two-way pagers, fax machines, and internet email.

3.1.3 Microwave Communication

The microwave bands constitute an enormous amount of bandwidth, which is at least 40 times the bandwidth that is available below the microwave bands, which is 1 GHz. However, the transmission of microwave is influenced by atmosphere: as signal travels through the atmosphere, it is attenuated by changes in air density and absorption by atmospheric particles. Also, raindrops absorb or scatter the microwave signal. These make microwave not suitable for long-distance communications. Both analog and digital microwave systems are available, but digital predominates in current products. A digital microwave system consists of three major components: the digital modem, the radio frequency unit, and the antenna. An available microwave communication technology for intermodal terminal is Automated Equipment Identification, which is currently used in some terminal gate operations.

Automated Equipment Identification (AEI) technology uses labels or tags and electronic scanners together. Labels or tags can store information and be attached to transportation equipment or containers, and scanners can retrieve information stored in labels or tags. These tags can be either passive or active: a passive tag transmits a signal whenever it receives a signal from an interrogator, whereas an active tag includes a battery and emits signals continuously over time. Figure 3.4 indicates different types of tags and scanners as well as their installation position. In 1987, a study conducted for the Association of American Railroads by Martland investigated the potential benefits of using AEI in intermodal terminals. [EPAA87] At that time, rail freight cars were all equipped with bar codes. According to this study, AEI technology has greater reliability, durability and effectiveness compared to bar code, but it is impossible to tag all containers and trailers because it would be too expensive; temporary tags may however be a feasible way to implement AEI technology. Today, RF tags are commonly used in intermodal freight transportation. Since 1995, all railroad cars and locomotives have been equipped with radio frequency (RF) AEI tags that transmit vehicles' identification to a wayside scanner [ELSP96]. The AEI scanners "commonly operate at a speed of 30 miles per hour in a distance of 10 feet, and it can be designed for speed greater than 100 miles per hour and distances greater than 50 feet". [EPAA87] Amtech Systems, the AEI provider, states, "By using Radio Frequency (RF) systems, AEI can achieve the accuracy rate as high as 99.95%". [ELSP96] The tag now stores 120 bits (which could be increased easily by current technology) of user data and can be reprogrammed in the field up to 10,000 times. [AEIC01]. Thus AEI could be used to manage traffic flow through gates and to track yard equipment for improved cycle time and productivity in intermodal terminals.



Source: Amtech Systems Corporation, 1994

Figure 3.4 AEI Tags and Scanners

There are some different strategies to implement AEI technology. For example, the temporary AEI tags may be placed on each trailer, container, truck or chassis when it enters the yard, then someone could walk or drive around the parking area using a scanner to record the vehicle numbers. When the trailers leave the terminal, the tags would be collected and saved for use on other equipment. Another implementation is to place permanent tags on not only rail locomotives and cars, but also on all containers, trailers, chassis, more terminal equipment and other intermodal equipment.

Scanners could be installed at terminal gates, at rail entrance to the yard, along the rail right-of-way, and throughout the terminal parking and apron areas. The scanners can also be placed on terminal's vehicles. To retrieve as much as information from identifying the equipment or vehicle by tags, we need to revise the database system connected to the AEI scanners, the terminal management information system should contain the type, dimension, category, history, schedule, status, position, and much more other information of the equipment and vehicles, so that it can provide valuable information to the terminal operator or other customers. For example, the system at pre-gate could assign a temporary unique ID for an incoming vehicle that is waiting for entering the gate, and this information and data gathered from video camera as well as information from transportation companies are transferred to the gate operating system through local area network, so that when the vehicle arrives at the gate, all its information is available in the query of database and is shown to the gate operator. At the same time, the documents needed to go through the gate and the storage spaces allocation direction are also printed out and are available to be handed out to the driver.

Based on cost estimation, temporary tags for terminal operation is still a more economic choice than permanent tags, and it is feasible today. If the cost of AEI tags could be decreased dramatically in the future, by using permanent AEI tags and DGPS technology, cargo and vehicle position and status could be tracked not only within intermodal terminals, but also almost all over the world. Through the network and database of intermodal terminals and transportation companies, the containers or vehicles could be tracked by DGPS when they are moving outside the terminal area, and be located by AEI scanned information in the database when they are laying within the terminals.

3.1.4 Video Systems

Video and images are more powerful to describe real situations than numbers and text in some circumstances. For example, terminal managers in control centers could monitor the processes at the gate and tracks continuously through video systems, while normal data can only provide managers with limited information as numbers and text. Images can clearly illustrate the situation of an accident, while numbers and text can hardly give the reader impression as good as images with the same amount of data. In addition, advanced artificial intelligence technology can help to identify some special equipment or vehicles by image or video, which can be used to recognize suspicious vehicles or people, bring the issue to a security clerk, and increase the security of intermodal terminal management.

People have worked on the video and image compression standard for a long time and achieved great progress. Combined with development of high-speed networks, the transmission of video and images is no longer expensive. Full motion, full-color video requires a 6 MHz analog channel or a 1.544 Mb/s digital channel. With sacrifice in clarity during motion, digital bandwidth can be reduced to as little as 64kb/s. At least T1 bandwidth (1.544 Mbps) is needed for a satisfactory signal that is approximately equal to the quality of a home VCR and at least two 64kb/s channels are needed for minimally acceptable videoconferencing. ITU's H.261 is intended for videoconferencing, MPEG-1 and MPEG-2 are intended for broadcast or narrowcast video. MPEG-1 compresses a video signal into bandwidth of up to 2Mb/s. The resolution is 288 lines/frame, which is home VCR quality. MPEG-2 compresses a high-definition television signal, which normally would require 25 MHz of analog bandwidth, into the 6 MHz channel allocated to broadcast television. Moving Picture Experts Group (MPEG) has produced "MPEG-1, the standard on which such products as Video CD and MP3 are based, MPEG-2, the standard on which such products as Digital Television set top boxes and DVD are based, MPEG-4, the standard for multimedia for the fixed and mobile web and MPEG-7, the standard for description and search of audio and visual content. Work on the new standard MPEG-21 Multimedia Framework has started in June 2000". [MPEG01] The Joint Photographic Expert Group (JPEG) has scheduled to release JPEG2000, which is claimed to be "capable of compressing an image to two percent of its original size by using wavelet compression technology." [JPEG01] As stated by Taubman and Marcellin, "The JPEG 2000 initiative is intended to provide a new image coding system using state of the art compression techniques, based on the use of wavelet technology. " [JPEG00]

Cable Television (CATV) system is a typical video system, and it has three components: head-end equipment, trunk cable, and feeder and user drop equipment. Closed-circuit television (CCTV) is a prospective application for intermodal terminal management. The video image provides a lot of information that data can hardly describe, such as the congestion, accidents, status of equipment and vehicles, space conditions, etc. Analog CCTV video is difficult and costly to distribute to other terminals or companies.

Although analog multiplexers can support add/drop through channel frequency selection, the whole process requires a special infrastructure and electronics—video overlay network, which is expensive to deploy and requires special maintenance skills.

Digital CCTV is a better choice, and the real-time, compressed digital processing would be economically supported by high-speed digital signal processing technology. The compression standard is developing quickly. As we talked above, several public standards have been published for video compression. In addition, the price of digital camera and digital camcorder has dropped significantly in the last several years and is expected to continue decrease and become more affordable. Gigabit optical Ethernet evolved and the 10-gigabit Ethernet standard is emerging, and they can support the transmission of digital video and digital images throughout the internet.

3.1.5 Fiber-Optics Network Technology

Today, every major industrialized center is linked to the rest of the world with fiber-optics cable, with the resulting high-quality, low-cost circuits. The default method of linking Local Area Network hubs is fiber. An emerging standard, Fibre Channel, provides speeds approximating 1~100 Gb/s for interconnecting data hosts and peripherals.

Fiber optics provides high bandwidth, and provides interference-free communications with one level of quality. The cable is fabricated from silicon, an abundant substance on the earth. Best of all, it can be expanded to many times its original capacity as the multiplexing electronics improves. A few years ago, 1 Gb/s was the state of the art in fiber-optic capacity. Now, OC-192 at 10 Gb/s is feasible, and the capacity of the fiber can be increased with dense wave division multiplexing.

Fiber optics communication system have applications in both private and public communication systems, based on the standards of SONET/SDH, FDDI, Fibre Channel, and LAN protocols. The sample applications are: long-haul transmission, intercontinental and undersea transmission, trunking between local central offices, metropolitan area backbone systems, local area networks, cable television backbone transmission, short-haul data transmission through noisy environments, Fibre Channel for high speed computer communications, etc. [TIHT00]

The available network technologies are listed in the following two tables. Table 3.2 listed the access technologies (the connections from LAN to WAN) and their characteristics as well as their advantage and disadvantages. Table 3.3 listed the characteristics of integrated technologies for network (WAN). Network data communication users can choose the suitable network with their unique requirements (bandwidth and speed) with acceptable prices for equipment installation and maintenance.

Access technology	**Upload speed**	**Download speed**	**Initial/ Monthly cost**	**Pros**	**Cons**
ADSL	90kbps-1.5Mbps	768kbps-7Mbps	$100-500/ $50-500	Use existing phone lines; dedicated bandwidth; always on	Immature; distance and line limits
Cable modems	128 kbps-10Mbps	500 kbps-30 Mbps	$100/ $50	Easier installation; always on	Shared medium
Dialup modems	28 kbps (to be 40 kbps)	56 kbps	$100/ $20	Ubiquitous	Slow, require connection each time
IDSN (BRI)	56-128 kbps	56 kbps-128 kbps	$300/ $50-100	Mature	Difficult to configure; expensive
Leased lines (T1 and fractions)	56 kbps-1.5 Mbps	56 kbps-1.5 Mbps	$2,500/ $500-1,000	Mature, ubiquitous	Expensive
Satellite	--	400 kbps	$1,000/ $50	Truly ubiquitous	One way
Frame relay	64 kbps-1.5 Mbps	64 kbps - 1.5Mbps	$500-1,000/ $50-500	Reliable	FRAD expensive
SMDS	1.7 Mbps-34 Mbps	1.7 Mbps-34 Mbps	$10,000/ $1,000	Handles bursty traffic	Metro areas only; to be superseded by ATM

Source: MIT Class 1.264 Lecture Notes, Sep 2001[MITL01]

Table 3.2 Network Access Technologies

Integrated technology	**Bandwidth**	**Initial/ Monthly cost**	**Pros**	**Cons**
FDDI	100 Mbps	$1,000/ $0	Cheap, stable, LAN extension	Dark fiber often unavailable
ATM	25-1200 Mbps	Variable, Expensive	Highest bandwidth	Very expensive, though cost is dropping
Switched 56	56 kbps	$1,000/ $50	Stable	Not upgradable
Fractional T1	64- 768 kbps	$1,000/ $300-800	Expandable	Expensive
T1	1.544 Mbps	$2,500/ $1,000	Stable, available	Expensive, can be hard to utilize fully
T3	45 Mbps	$50,000/ $7,500	Fastest private network	Expensive

Source: MIT Class 1.264 Lecture Notes, Sep 2001 [MITL01]

Table 3.3 Network Integrated Technologies

FDDI is affordable and fast technologies for network-integrated technology. When the dark fiber is available, it is an excellent choice for the fibre-optics communication of ITMIS. With the fast development of Fibre Channel, it is possible to transfer big volume of data in the network. Thus the information gathered from video cameras around the intermodal terminal can be processed and compressed correctly, and be transferred to other terminals or carriers. It means the shared information among companies could be more precise and detailed than current applications, and more sophisticated information analysis tools are needed to extract useful information from image and video data to assist the terminal management.

3.2 Other Technologies

Information Technology can help to automate the verification and inspection of drivers, truck tractors, trailers, containers, and chassis moving into and out of the terminals. It can also help the automation of operations within the intermodal terminals.

One simple strategy to solve the capacity problem in intermodal terminals is to change the operating time from 5 days per week, 12 hours per day to 7 days per week, 24 hours per day. However, this strategy meets the problem of crew schedules in some terminals, so that it has not been widely implemented on the current terminal operations.

Information technologies and information system could help to achieve better crew utilization. By using automatic control, the crew requirement could be cut to a minimum number; some benefit of safety could also be obtained by the technologies because less crew on the ground means less probability of injury. By using video cameras, real time information of crews could be gathered; by querying the terminal information system, plans and availability of crews could be investigated. Based on plans and real time crew information, crew scheduling optimization model could run automatically to provide terminal managers more efficient schedules, and adjust scheduled plans according to accidents or unexpected condition when implementing crew plans.

3.2.1 Remote Controlled Locomotive

In the Canadian National Railway website [CNNR01], it is defined that "BELTPACK® is a computer-based locomotive remote control system that allows control of locomotives by ground-based employees via radio link using a portable operator control unit (OCU). The technology enables two operators to operate a switching assignment safely, by use of an onboard computer." BELTPACK® has been implemented in Canada rail terminals in 35 systems and operated for millions of hours. The locomotive is equipped with an onboard microprocessor, and ground based employees can control the locomotive via radio link.

CANAC Inc, the BELTPACK® provider, stated that the technology "provides direct means for the train crew to control the acceleration and deceleration of a locomotive without the need for relaying signals to an engineer. Its preset coupling speed protects rolling stock and cargo, and the system's archive memory stores vital information. It is also programmed with full integration of train handling expertise." [CANA01] Based on the statistics of CANAC Inc, with more than 2.5 million hours of operation on Class 1 railroads, the system is proved to be safer (47% less accidents vs. conventional locomotive), and it can save operating cost by reducing the labor operating time, thus it is more efficient (more than $25 million of operating savings for one year).

Remote controlled locomotives demonstrated could provide cost savings and a quick payback, but they still need two people working on the ground for the movement of each locomotive. A possible improvement of this technology is to implement the remote control by crews inside the terminal control center, instead of by crews along the ground. Digital video cameras and sensing equipment along the rail would ensure safe and accurate movements. And this improvement will provide terminal continuous operation possibilities (be operated 24 hours per day, 7 days per week) without inducing more labor cost than regular operation.

In intermodal terminals, remote control locomotives could be used in rail car switching from the train entering the terminal until the train leaving the terminal. Automated locomotives can lead the trains enter the terminal and go to the loading or unloading track, without wasting the driver's time for waiting in the queue. This technology provides direct means for the operation crew to control the acceleration and deceleration of a locomotive without the need for relaying signals to an engineer. Because the locomotive and cars will move along the track, it is similar to the AGV technology but it does not need installation of directed path under road. Instead, some sensors should be installed along the rail.

3.2.2 Automated Guided Vehicles System

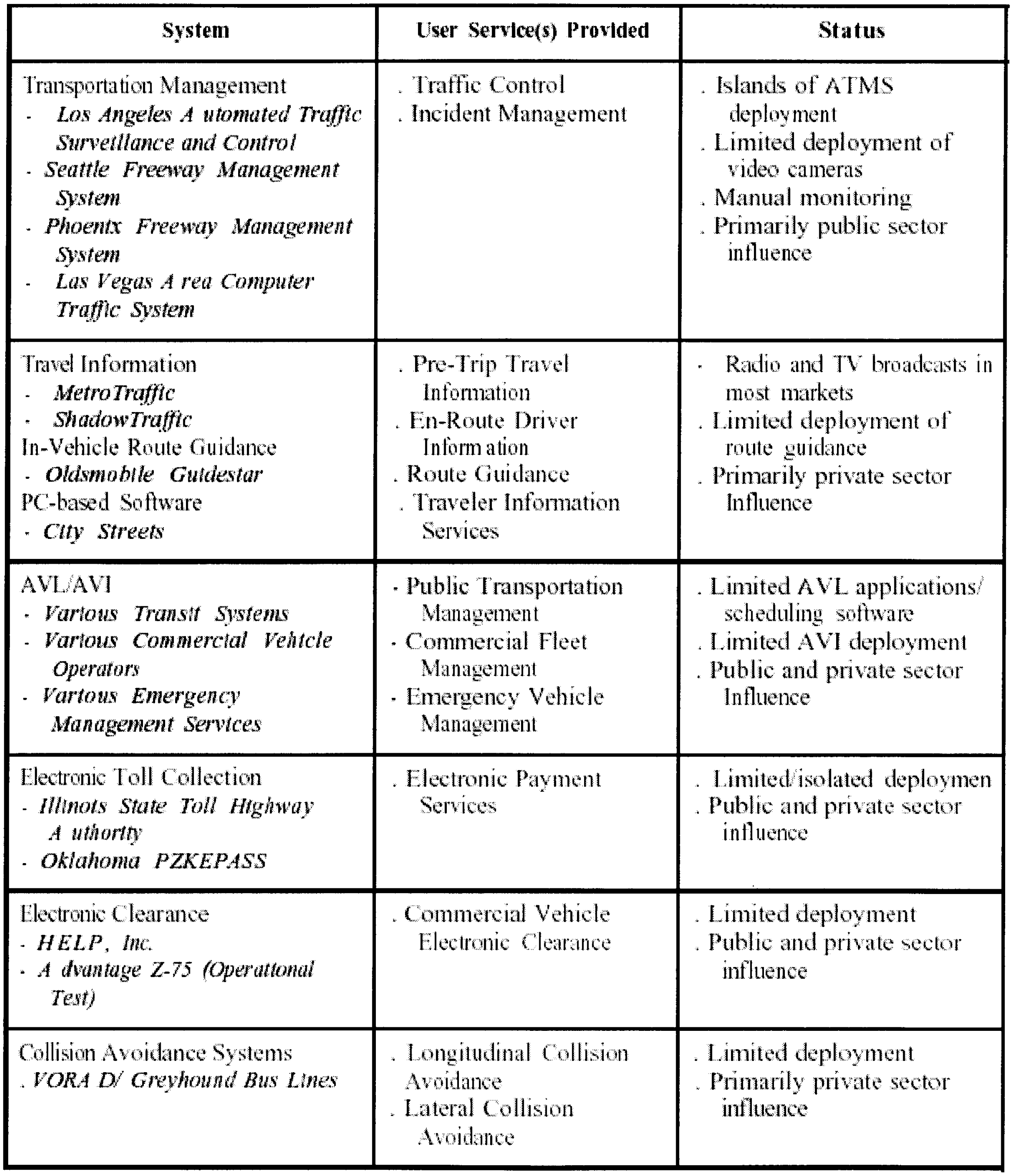
Automated Guided Vehicles (AGV) system has been installed in various industrial manufacturing plants since 1970 and the technology is continuously developed. AGV system generally includes vehicles, navigation system and guide path, automated controls, obstacle detection system, and appropriate interfaces with other terminal operation systems. The wireless transmissions between the onboard computers on each AGV and the control center allow the vehicle to navigate to almost any point within the terminal.

The benefits of AGV system include increased efficiency, reduced labor costs, improved safety, and better inventory tracking. AGV efficiently share aisles and work areas with people and truck traffic, smooth the cargo movement inside the terminal, and are generally suited to repetitive actions. AGV can offer a safe and reliable alternative to human operators, and made the tracking of cargo safer and more precisely because the human error, one of the big error resources, is prevented. In one word, AGV system provides efficient and flexible maneuvering with less manpower, higher container throughput at reduced costs, continuous operation possibilities (24 hours a day, 7 days a week), and consistent container handling operations.

In intermodal terminal management, the digital CCTV system could help to ensure the safe operation of automated guided vehicles, and the AEI technology could make the AGV operation in the terminal faster because real time cargo locations can be achieved very easy from the central information system. AEI tags could also be equipped on AGV so that their position and movement can be tracked by scanners all over the terminal, thus optimized operating plan of AGV can be made based on information of both cargo and AGV. AGV are highly maneuverable and can be equipped with DGPS receivers to track their movements and location throughout the yard. Thus AGV systems could be used in terminal operations for the retrieval and storage of containers, but it is an expensive system suitable for large terminals.

3.2.3 Coordination of Information Systems in the Intermodal Network

There are many information technologies and systems implemented in separate intermodal network components. Table 3.4 was developed by Cambridge Systematics Inc. for illustrating applications of ITS in intermodal freight transportation as of 1999. There are many application examples shown in the table, but they tend to be isolated “islands” of technology and system. It would be better for these systems to coordinate together at some point in the intermodal network. If these technologies and information could be used in the information system of intermodal terminal management, the information shared among these systems and intermodal terminals could help to optimize the network performance.



System	User Service(s) Provided	Status
Transportation Management - *Los Angeles Automated Traffic Surveillance and Control* - *Seattle Freeway Management System* - *Phoenix Freeway Management System* - *Las Vegas Area Computer Traffic System*	. Traffic Control . Incident Management	. Islands of ATMS deployment . Limited deployment of video cameras . Manual monitoring . Primarily public sector influence
Travel Information - *MetroTraffic* - *ShadowTraffic* In-Vehicle Route Guidance - *Oldsmobile Guidestar* PC-based Software - *City Streets*	. Pre-Trip Travel Information . En-Route Driver Information . Route Guidance . Traveler Information Services	- Radio and TV broadcasts in most markets . Limited deployment of route guidance . Primarily private sector Influence
AVL/AVI - *Various Transit Systems* - *Various Commercial Vehicle Operators* - *Various Emergency Management Services*	- Public Transportation Management - Commercial Fleet Management - Emergency Vehicle Management	. Limited AVL applications/ scheduling software . Limited AVI deployment . Public and private sector Influence
Electronic Toll Collection - *Illinois State Toll Highway Authority* - *Oklahoma PZKEPASS*	. Electronic Payment Services	. Limited/isolated deploymen . Public and private sector influence
Electronic Clearance - *HELP, Inc.* - *Advantage Z-75 (Operational Test)*	. Commercial Vehicle Electronic Clearance	. Limited deployment . Public and private sector influence
Collision Avoidance Systems . *VORA D/ Greyhound Bus Lines*	. Longitudinal Collision Avoidance . Lateral Collision Avoidance	. Limited deployment . Primarily private sector influence

Source: Cambridge Systematics, Inc [COIT99]

Table 3.4 Examples of Current IT Deployments

The electronic toll collection systems use radio frequency ID transponders and transaction processing software. These systems are used to expedite throughput, minimize queuing and delay, reduce travel time, fuel consumption, traffic congestion and the risk of accidents at toll barriers. Similar systems are in place at weigh stations and international borders for automated screening of trucks. [COIT99] Since the similar technology of radio frequency ID transponders could be used in intermodal vehicles in ITMIS, standard AEI tags could be used in all over the intermodal network; the information in central database could also be shared among terminals and other components in the network.

Shipment tracing and information systems manage the flow of materials and products from source to user, they are used to optimize the visibility and control of freight and containers, trucks, ships, etc. Motor carrier routing and dispatching systems automate the routing and dispatching of trucks. The systems use scheduling algorithms, geographic information system, and linear optimization software to match drivers, equipment, and loads to pickup and delivery windows, minimize travel time and cost, and schedule maintenance. Asset location and management systems can locate and track a vehicle or container. The systems are also used to estimate times of arrival, minimize out-of-route travel, optimize equipment use, and improve safety and security. Some systems are coupled with onboard computers and sensors that monitor vehicle or cargo condition. Because intermodal terminal information system may need DGPS to track the position of vehicles and containers, the GPS receivers already equipped can be used to save cost, and the data in these information systems can be used to improve the terminal management as well.

Incident management systems use CCTV, automatic detectors, cellular phones and variable message signs to enable officials to quickly and accurately identify a variety of incidents, spread information about an incident, then reduce the impact of incidents on traffic flows. Hazardous materials response systems provide information to emergency response personnel at the scene of an accident about the contents of a hazmat load. Safety assurance systems provide information on the safety history and performance of motor carriers and drivers. If intermodal terminals can obtain the information of these systems, the terminal management would be safer and more efficient.

To improve terminal gate operations of inbound and outbound flow management, we can connect the information system of intermodal terminal management with electronic toll collection system, weigh station clearance system, motor carrier routing and dispatching system, and traffic management system. The electronic toll collection system enables the electronic payment of highway, bridge, and tunnel tolls. The weigh station clearance system enables commercial vehicles to avoid stops at weigh stations. The motor carrier routing and dispatching system automates the routing and dispatching of trucks. The traffic management system regulates traffic signal timing and coordination in a corridor. Cooperating with these systems, the gate operation can automate the verification and inspection of drivers, trucks and containers, so the queue time at terminal gates, congestion on egress roads, terminal peak labor costs and fuel consumption can be reduced, and safety on access and egress roads can be increased.

The information system of intermodal terminal management could increase terminal capacity by facilitating higher utilization of all resources and smoothing the peak demand; as a result, there will be less slack time in the schedule, and it may be more difficult to recover from accidents, unexpected peak loads, and other service disruptions. Hence, response to emergencies is more important for a highly utilized terminal. To ensure the safety of freight and provide quick emergency response, we could connect the information system of intermodal terminal management to incident management system, safety assurance system, and hazardous materials response system. The information system of intermodal terminal management could plan and track the location of hazmat containers aboard ships or inside terminal storage spaces. Thus the delays could be reduced due to less incidents and congestion in highway, the fleet operating efficiency and the safety of personnel could be increased, the incident response or clearance would be improved, the restoration of normal conditions would be faster, and better customer relationship management can be achieved for intermodal terminals.

3.2.4 Data Mining Technology

We have tremendous amounts of data concerning traffic flows, terminal operations, and performance of the intermodal system. Data have been collected since 1970s (e.g. Reebie Associates created and is maintaining a database with information of different modes of freight transportation flows at county level, and commodity flow surveys were conducted in 1993 and in 1996 for the United States freight transportation by the Bureau of Transportation Statistics) and are available for further analysis. If we construct the information system of intermodal terminal management, we could have more detailed data available. Intermodal transportation involved in big information systems. Data mining technology has been proved valuable in other areas like airport safety, highway traffic control, incident detection, etc., but has not been implemented in rail intermodal area so far.

Data mining could bring great benefits for rail intermodal terminal performance. For example, we may get the following potential benefits for terminal operators by using data mining:

- Time patterns recognized from data mining applications can be used for resource demand forecasting and resource assignment.
- Commodity patterns can be used for lifting equipment allocation and storage spaces management
- Characteristics of freight flow can be used for regional terminal cooperation and new terminal design

There are also potential benefits from data mining for carriers, such as:

- Principle factors identified for freight revenue can be used to improve efficiency and optimize the transportation
- Patterns of Origin-Destination commodity flow and their characteristics can be used for transportation network optimization

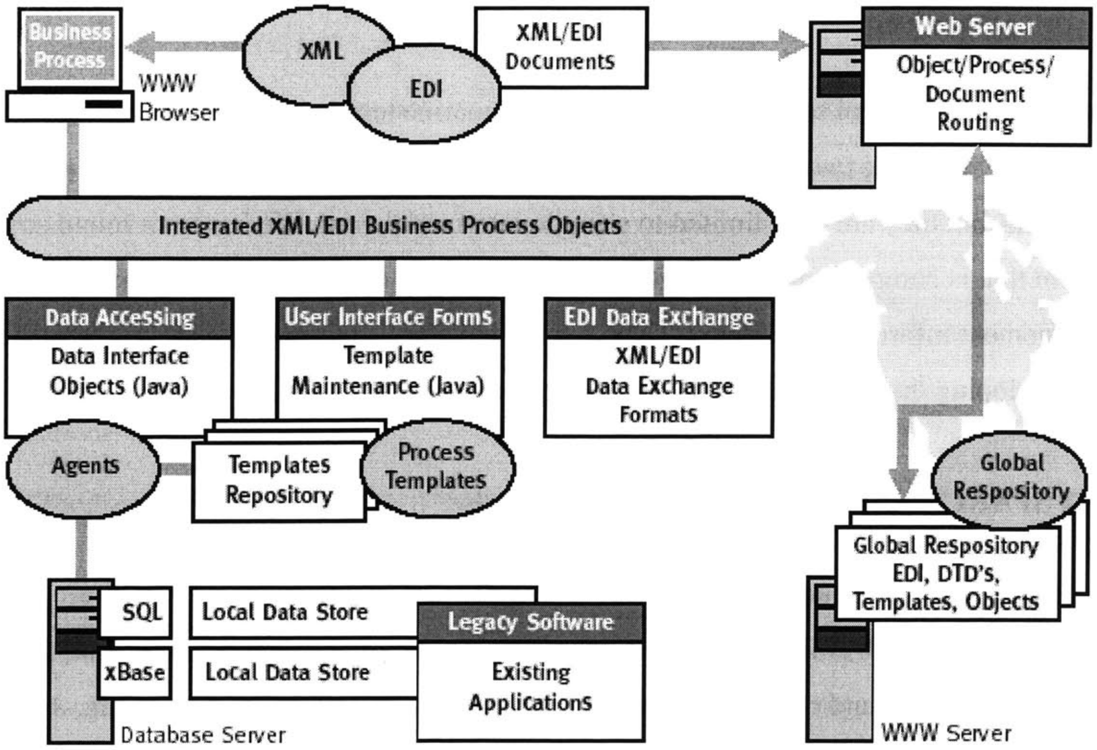
In sum, there are a lot of potential application areas of data mining in intermodal terminals and in intermodal freight transportation networks. This new technology could be helpful for improving future operations and management by using historical data and artificial intelligence models.

3.3 Data Exchange Protocol

Traditionally, big companies are using Electronic Data Interchange (EDI), which is able to express data in a simple format and send it to other people, so they can interpret the received information. However, setting up traditional EDI is an expensive and time consuming manual process as the company attempts to synchronize their internal systems with the external systems of their partners. EDI failed to create a broad based acceptance mainly because of its expensive cost, limited data integrity and accessibility, and limitation of extendibility.

Extensible Markup Language (XML) is a World Wide Web Consortium (W3C) proposed recommendation for a file format to easily and cheaply distribute electronic documents on the World Wide Web. O'Reilly XML.com defines it as "XML is the Extensible Markup Language. It is designed to improve the functionality of the web by providing more flexible and adaptable information identification. It is called extensible because it is not a fixed format like HTML (a single, predefined markup language). Instead, XML is actually a 'metalanguage', a language for describing other languages, which lets you design your own customized markup languages for limitless different types of documents. XML can do this because it's written in SGML, the international standard metalanguage for text markup systems (ISO 8879)". [OXML01]

XML/EDI can exchange not only EDI data, but also process control templates, thus enabling underlying processed information. Because the leading web browser products, e.g. Microsoft Internet Explorer and Netscape Navigator, already support XML in their latest releases, XML/EDI is deployable to anyone with a web browser and internet connection. A sample XML/EDI system is described in Figure 3.5.



Source: David RR Webber, Introducing XML/EDI Frameworks [IXEF98]

Figure 3.5 An Integrated XML/EDI Internet System

With excellent compatibility to existing EDI transactions, XML/EDI provides smarter, cheaper and more maintainable systems. Thus we do not have to discard the investment in existing EDI systems, but can enjoy the benefit of new XML/EDI system. Some intermodal terminals and big carrier companies are using EDI, so they can easily move forward to XML/EDI.

The information system of intermodal terminal management could choose XML/EDI as its data exchange standard. XML/EDI can exchange not only EDI data, but also process control templates, thus enabling underlying processed information.

3.4 Terminal Control Software

Some terminal control software are available for marine terminals. The best we could find is the following two software bundles. They have been used by some intermodal terminals, but they are both limited to a single intermodal yard. We have not found any system that is comprehensive enough to be used directly in the intermodal terminal management information system (ITMIS), but we could use these software as references for developing the ITMIS since many functions are similar.

3.4.1 SPARCS-EXPRESS for Marine Terminals

Navis developed an "integrated, real-time container terminal system" SPARCS-EXPRESS suite, [NAVI01] which handles many aspects of terminal management, from graphical planning and control to comprehensive transaction and data processing. As claimed in Navis website, the software suite is licensed to more than 40 marine terminals worldwide.

Synchronous Planning and Real Time Control System (SPARCS) is a graphical planning and control solution for container terminals. SPARCS offers a comprehensive range of options: vessel planning, yard planning, rail planning; equipment handling control, dispatch and control via radio data terminals, crane and berth scheduling and monitoring, detailed error checking, sophisticated HazMat segregation, EDI support, graphic simulation of what-if scenarios, real-time information sharing, advanced reporting capabilities, etc.

Navis argued that SPARCS can "minimize the number of handlings per container and equipment idle time, get planners working concurrently in real time to produce vessel and yard plans quickly and accurately, and optimize vessel and rail planning, yard allocation and equipment dispatch with minimal human intervention" and can help to "optimize the utilization of labor, yard space, and handling equipment to maximize terminal's efficiency, productivity, and profitability". [NAVI01]

EXPRESS is a comprehensive information system for container terminals. It manages and maintains many terminal business transactions while adapting to unique procedures and business rules. EXPRESS offers a comprehensive range of options: gate operations management, work order management, import/export processing, billing and bookings management, interactive voice response, EDI management, yard, vessel, and rail operations management, equipment management, container freight station management; break bulk management; advanced reporting, etc.

Navis claimed, "The dynamic reporting capabilities built into EXPRESS enables terminal managers to track performance, improve customer service and increase profitability. It can accurately record and invoice all transactions and services, supply interface with gate technologies to expedite truck processing, optimize productivity by eliminating paper-based tracking and human error, and give the customers secure, customized, on-line access to place bookings, request terminal services, and make status queries." [NAVI01]

3.4.2 Terminal Automation System

Terminal Automation System (TAS) is developed by Sea-Land Service, Inc. Cerwonka from Sea-Land Service [TAS96] described it as "a total terminal system providing a horizontal structure through each area in the terminal hub. Timely information is a key element of TAS for successful management decision-making and ongoing analysis for continuous productivity improvement. The basic philosophy of Terminal Automated System (TAS) is to approach terminal operations from a hierarchical design."

The TAS modules include:

a. Gate in module, which captures information of truckers, visit types, missions, and equipment.
b. Gate out module, which provides real-time confirmation updates, and maintains accurate equipment status as well as inventory control.

c. Inspection module, which collects equipment damage information, truckers' signatures, and other optional data (e.g. seal number, placard information, and receiving temperature).
d. MRCS module, which receives detailed information about equipment condition from inspection and estimates the time and materials needed for any repairs.
e. Yard inventory module, which captures real-time equipment location information by using portable computers and radio frequency communications to the TAS database.
f. Marine module, which processes information during vessel discharge and stow operations using portable computers and radio frequency communications to confirm equipment discharged and stowed on a vessel.
g. Expert module, which manages all yard parking activity.
h. Inbound cargo release module, which provides information to the gate-in and gate-out modules regarding the status of inbound cargo.
i. TAS archival/retrieval system module, which enhances data captured in the TAS system to provide management information to terminal personnel.
j. Workstation stowage module, which provides a standalone vessel stowage facility with a graphical user interface.

In the same paper, [TAS96] Cerwonka stated the benefits of TAS: "It is anticipated that TAS will provide benefits in two basic areas of terminal operations: productivity improvements and cost reduction. It would reduce labor costs and overtime costs, improve marine productivity, eliminate pneumatic tubes, make automated selection of empties for dispatch, and enhance maintenance and repair."

3.5 Summary

When handling containers, the terminal operators perform three primary tasks: identification, location and assignment. Many research have been done with the optimization of container assignment, and some terminal software is invented as we mentioned in this chapter. To use these methods more effectively, accurate information concerning containers and terminal resources is necessary. We may use advanced information systems to achieve the real time information as a decision reference for the operators, or as data entry for automatic control models.

To ensure the accuracy of data gathering and transmission, several information technologies are needed to be combined into an information system. Thus it is important to investigate available technologies as well as their capabilities of implementation in intermodal terminals. In this chapter, I introduced characteristics and capabilities of several information technology such as communication technologies, video systems, automated guided vehicles, etc., and discussed integrated information system in intermodal terminal network, data exchange protocols, and terminal control software development. These technologies could possibly be used to help the data transmission and information sharing for intermodal terminal management information system (ITMIS), which will be proposed in the next chapter.

Chapter 4 Intermodal Terminal Management Information System

Because infrastructure construction is expensive and can hardly keep up with rapid growth in demand, information sharing and other IT technologies would be helpful in mitigating congestion or heavy load on intermodal terminals. In this chapter, I propose an Intermodal Terminal Management Information System (ITMIS), which is a system that can gather many kinds of information useful for terminal management, and provide seamless information transmission and help information sharing among transportation partners. ITMIS will be very helpful for urban area terminals over the next 5 or 10 years because new infrastructure construction can hardly be implemented so fast; ITMIS could also be helpful in the long-range planning of terminal management.

In the first section, I will describe the architecture design of Intermodal Terminal Management Information System and illustrate some communication technologies that are suitable for the system based on current capabilities. The core component of the ITMIS, central information system, is described in the second section. In the third section, the system modules for data entry, reservations, queries, and terminal management are introduced.

4.1 System Description

4.1.1 ITMIS Overview

The basic architecture of the Intermodal Terminal Management Information System (ITMIS) is shown in figure 4.1. The core component of ITMIS is a central information system, which holds all the information for terminal resources, cargo inside the terminal, and carriers who pick up or drop off cargo in the terminal. The central information system provides a graphical user interface to customers, draymen, train operators and shippers, so that they can make queries and find useful information, reserve terminal resources, or enter their expected arrival/departure time to the central system.

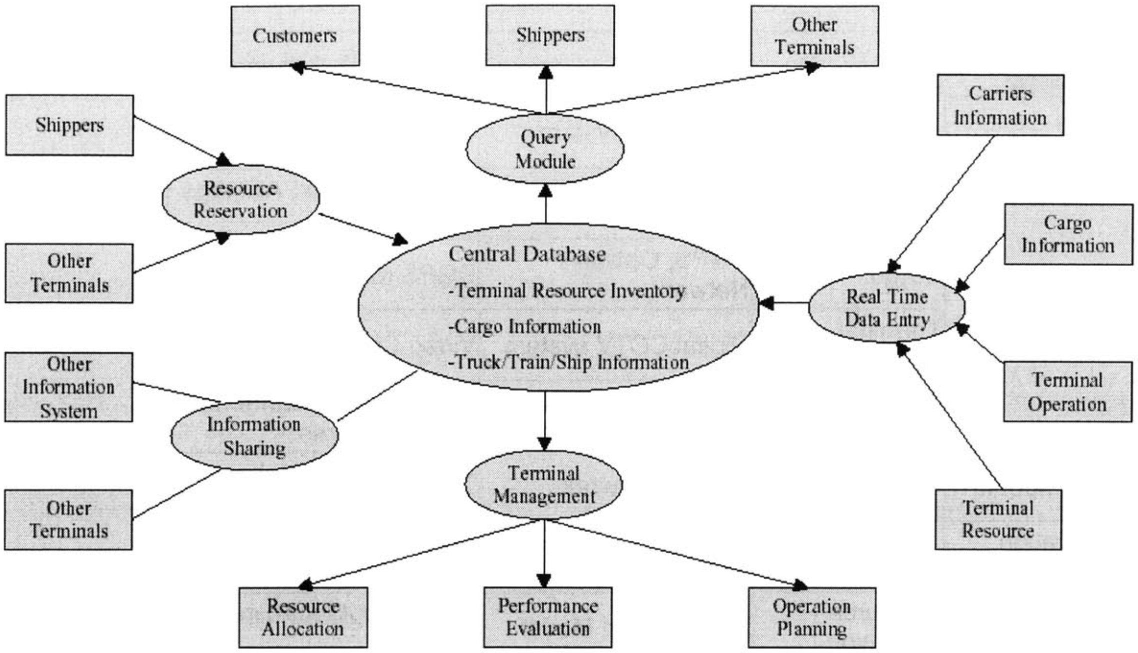


Figure 4.1 ITMIS Architecture Descriptions

The data entry module collects real time information; the query and reservation modules provide carriers and terminal managers valuable information for planning and scheduling; terminal management module gives terminal managers an operating platform. Terminal managers can make queries from the central database, then use software or models to make resource assignments, operating plans or check terminal performance. Each ITMIS has a connection to other information systems and other terminals, so that information could be shared among different systems or among terminals. Table 4.1 illustrates capable technologies for each module of ITMIS.

System Component	Sub-Component	Technology	Hardware & Software
Central Database		Database System	Database Server
Data Entry Module	Carriers	DGPS, AEI, Optical Network	DGPS receiver, AEI tags and scanners
	Cargo	DGPS, Optical Network	DGPS receiver
	Terminal Operation	Digital CCTV system	Video Cameras
	Terminal Resources	AEI, Digital CCTV system	AEI tags and scanners, Video cameras
Query Module		Optical Network	Web Server, Database Server, XML/EDI
Reservation Module		Optical Network	Web Server, Database Server, XML/EDI
Terminal Management Module	Resource Allocation	Optimization Model	Resource Allocation Software
	Performance Evaluation	Evaluation Model, Data Mining	Corresponding Software
	Operations planning	Optimization Model	Planning Software
Information Sharing Module		Optical Network	Web Server, Database Server, XML/EDI

Table 4.1 Capable Technologies for ITMIS Modules

4.1.2 ITMIS Communication

Based on investigations shown in chapter 3, many IT technologies could be used to improve data transmission related to terminal operations and information sharing in the intermodal network. Because there may be large amounts of video or images transmitted within future terminal information system, ITMIS could use FDDI, which can supply 100Mbps data transmission speed, as the technology for local area network. Cable modem could be used as access technology to connect the query module and the data entry module from central system to the internet. Digital CCTV could be used inside the terminal to monitor the operation of gate processing, train loading/unloading, storage, and cargo movements, etc. Because microwave technology is suitable for short distance communication, AEI could be used to track the location and status of cargo and vehicles inside the terminal. For tracking vehicles outside terminals, carriers could use wireless or satellite communications; global satellite is especially good for long distance tracking (e.g. international shipping, air freight, transcontinental trains). Thus differential GPS could be used for gathering information for vehicles arriving or leaving the terminal. Automatic optimization models could be used for terminal resource allocation, operations planning, and crew scheduling. Details of these choices of technologies for ITMIS are shown as follows.

Optical Networks

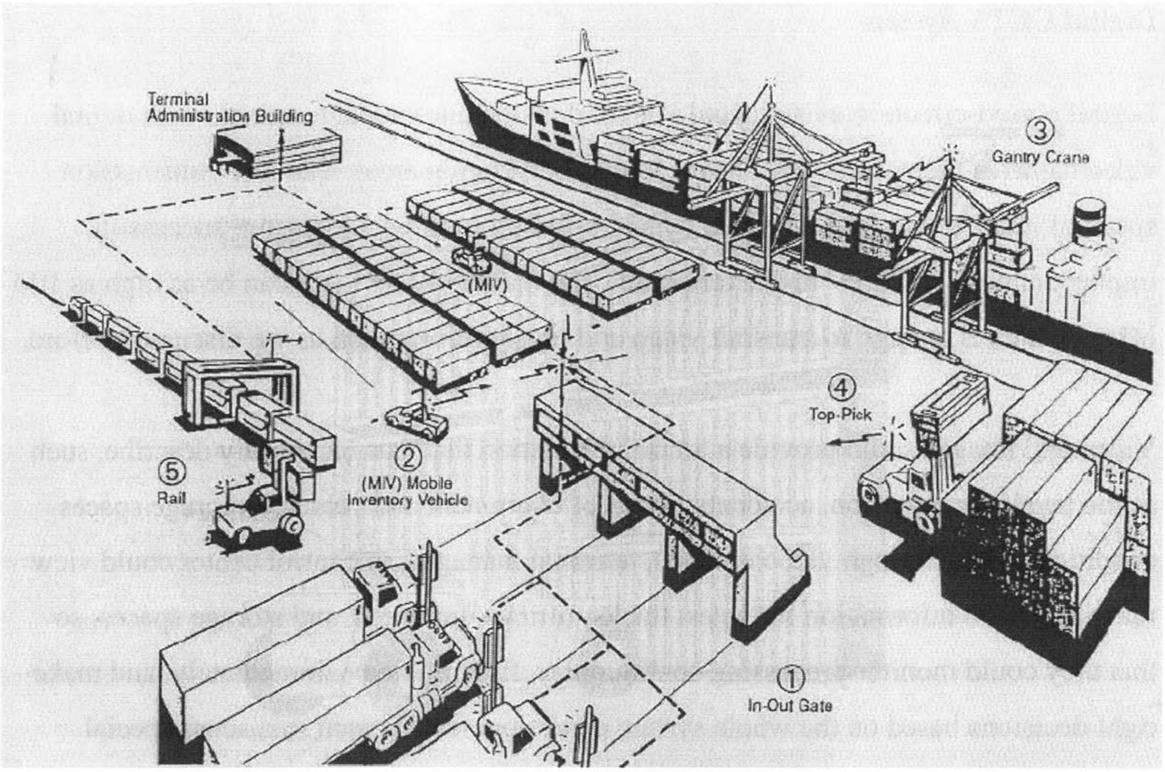
Because intermodal terminals are average about 40 to 45 acres with approximately 700 parking spots, [ITD01] we can use fiber-optics Local Area Network (LAN) for communications within terminals. For LAN inside the terminal area, or more generally, within the regional terminal area, we choose FDDI because it is cheap, fast and stable. The upload and download speed of the data transmission for FDDI are both 100 Mbps, which is enough to handle system transactions, and transmit data, voice, as well as video (128 Kbps is a reasonable estimation because at least two 64 Kbps channels are needed for minimally acceptable videoconferencing) and images (with JPEG format, 100K of image size is clear enough for terminal information transfer).

Because terminals are usually located in metro areas, it is easy and cheap to access the World Area Network (WAN) service. In a Local Area Network, communications can be very fast and the bandwidth can be as high as 100 Mb/s. Terminal managers also want to have network transferring information outside the terminal fast enough to handle high volumes of traffic including images. Cable modem could be selected as the access technology from LAN to WAN, and the terminal management information system could be connected to high speed network which uses Fibre Channel standard and provides 1~100 Gbps bandwidth. Thus a lot of information can be shared among terminals and carriers, even high volumes of video could be transferred through the fiber-optics network.

AEI & DGPS

Considering accuracy requirements, costs of installation and maintenance, and technology availability, ITMIS could use combined AEI and DGPS for cargo and vehicle tracking and positioning. More specifically, AEI tags and scanners could be used for locating terminal equipment inside the terminal and for their inventory control, because AEI is much cheaper than DGPS and it is more accurate and effective in limited range areas. DGPS technology could be used for collecting real time information of vehicles' position and speed outside the terminal, which is helpful in predicting exact arrival or departure times. All this information could be automatically entered to the central database with information collected from AEI scanners and DGPS receivers. Thus new data of intermodal equipment and carriers can be matched with the record in the database by their unique ID and the record can be updated.

ITMIS could use temporary radio frequency AEI tags for containers, trailers, and chassis that go through the terminal. The data in the tags will include equipment unique identification, current status (busy or empty) and position. Permanent AEI tags could be used for intermodal terminal equipment and vehicles such as locomotives and lifting equipment. The scanners could be installed at terminal gates, at rail entrances to the yard, along the rail right-of-way, and throughout terminal parking and apron areas. The scanners could also be installed on terminal's mobile vehicles, so that these vehicles can trace the inventory of terminal resources. Railroad companies have installed AEI tags on all locomotive and cars since 1995, and they also installed many scanners, so that we can make efficient use of this current equipment. The AEI provider, Amtech Systems Corporation, developed Figure 4.2, which shows a sample layout of AEI tags and scanners in a port.



Source: Amtech Systems Corporation [AEII94]

Figure 4.2 AEI Technology in an Intermodal Marine Terminal

DGPS could be used for ITMIS to provide exact real time position and speed for moving vehicles outside the terminal. Air and shipping companies are the leader for implementing this technology, and they have built up many ground stations all over the United States, so that intermodal terminals can use such technology without investing much money on GPS stations. This makes the technology cheaper to implement than expected.

Information collected from AEI and DGPS makes the strategy of "just-in-time" possible to be implemented on truck pickup and dropoff. Because ITMIS could gather information of transportation schedules and expected vehicle arrival or departure times, the terminal operator could send accurate information to carriers in advance. For example, trucks can arrive for dropoff just in time when the train is going to be loaded, or they can come for pickup as soon as the train is unloaded. This process would save not only storage spaces, but also resources of lifting equipment.

Digital CCTV System

Digital closed-circuit television could be used inside intermodal terminals with digital video cameras being installed all over terminal operation areas. The fast transmission speed of internet and modern video compression protocols could ensure successful implementation of CCTV inside terminals. The bandwidth of LAN can be as high as 100 Mbps, which is enough to transmit video and image information as we discussed before.

Video and images could provide a lot of information that data can hardly describe, such as the level of congestion, accidents, status of equipment and vehicles, storage spaces conditions, etc. Through video systems, terminal managers in control center could view real time video information for gates, tracks, lifting equipment, and storage spaces, so that they could monitor processing continuously, find problems immediately, and make right decisions based on the whole system condition. If they want to discuss special situations with other managers, they could use video and images transmission to clearly illustrate the situation of an accident or the level of congestion.

For example, idled equipment may be identified, and could be allocated to new activities if the previous schedule has not balanced the workload well. Unexpected special vehicles or containers that need extra care in terminal handling could be viewed directly from video cameras at the gate, and a special processing plan can be made for it to go through the terminal. Detailed information of dangerous cargo or equipment could be transferred to other companies by text and images. For terminal security, it is easier to identify suspicious people or vehicles in the intermodal terminal through digital CCTV system.

Video involved in congestion or accidents could be categorized and stored in backup tapes or CDs everyday for further analysis or research. For example, data mining could be used to find key factors that can cause loading or unloading delays. If using an effective compression standard, one CD can hold about 10 hours' video with 650 MB data. The cost of a blank CD is \$0.10 ~ \$0.20. If there are 20 digital video cameras in one terminal, the daily cost for video backup media is only about two to four dollars for an intermodal terminal.

4.2 Central Information System

The core element of the ITMIS is a central information system. All information would be stored in a relational database system and updated frequently. The system would then support convenient queries. Information in the system needs to be organized correctly, and it must include several basic parts of data as shown below.

4.2.1 Inventories of Terminal Resources

Scheduled plans and real time information of terminal resources are important for optimal resource allocation and achieving better terminal throughput. Combined with the resource reservation system module and connected to the terminal operations planning software, the management of terminal resource inventories could allow higher resource utilization and save operating cost.

The fixed facilities include: loading / unloading tracks for intermodal trains (track ID, length, scheduled occupation, current status, etc.), support yards for rail equipment (yard block, rows, slots, used area, reserved area, available area, etc.), storage spaces for containers, trailers, and chassis (slot ID, slot location, number of containers in the slot, reserved slot, current availability, etc.)

The terminal equipment include lift equipment (crane type, operating weight limit, location, reservation, status, cost per lift, etc.), mobile equipment (terminal vehicle ID, location, status, availability, etc.), locomotives (track ID, plan, status, etc.) and hostlers.

The resource inventories need to record not only the facilities and equipment in the terminal, but also the labor resource information. Labor data may include crew ID, crew type, scheduled work time, location, cost and status, etc.

4.2.2 Information of Containers, Trailers and Chassis

Once a container arrived at the intermodal terminal, its information such as location of storage slot, status and movement would be tracked and remain active in the system until it leaves the terminal. The RAILINC maintains Universal Machine Language Equipment Register (UMLER), which has the physical characteristics of 1.7 million rail cars, as well as 4.5 million trailers and containers for the intermodal freight transportation in the United States. Movement histories can be maintained as well: the container's current location could be entered to the system by automatic data entry, such as AEI scanner, terminal digital video camera, and DGPS, and all this information could be updated automatically. In general, all kinds of information can be retrieved by identifying the container by its unique ID. The sample information include: status of container (empty or full), transportation history, associated arrival carrier and departure carrier, pickup and dropoff time, origination and destination, weight, height, length, width, cargo type, storage spaces allocation, etc. Similarly, trailers and chassis information are typically tracked by identifying their unique ID.

4.2.3 Carriers Information

The third part of information stored in the central system is the information about trucks, trains or ships: scheduled arrival or departure times, current position, speed, expected arrival or departure times, cargo to pickup or dropoff, and terminal resources requirement. This information is different from the above two groups of data because it is collected from carriers outside the terminal.

The location and speed data could be used for terminal demand forecasting and operations planning. This information could be sent to the next carrier, who can arrange "just in time" pickup or adjust their departure time to minimize delays in pickup.

4.3 System Modules

4.3.1 Data Entry Module

The basic facility and equipment information of the terminal are obtained from current inventories and surveys. Because the number of storage spaces and terminal equipment life are fixed for a long period of time, maintaining this portion of the database would not be a problem.

The real time data entry is automated using fiber optic network, wireless communication and satellite communication. Technologies such as DGPS and AEI could allow accurate and precise information gathering and transmission. Real time information of terminal equipment could be updated by AEI tags on these equipment and AEI scanners along the road to terminal gate, as well as scanners all around the terminal. For example, when an equipment is passing through a scanner, the equipment would be scanned and identified by its unique ID; then information is loaded from the central system, and its status and location data is updated as well. The location of containers, trailers and chassis could also be tracked by AEI tags and scanners.

Carriers' information could be transmitted by satellite communication and wireless communication, because the vehicles are usually a long distance from the terminal, and it is not convenient to use fiber optics networks for moving vehicles. The ITMIS can be connected to the carrier's information system, which can use DGPS and other software to identify the position and speed of inbound vehicles, calculate their expected arrival times, and update the scheduled work plan for the terminal.

The digital video cameras could be installed along the rail yard, storage spaces, terminal gate, and road inside the terminals. Thus the operation of truck pickup or dropoff, train/ship loading or unloading, storage, and crew actions can all be monitored by the manager in terminal control center, and valuable video data are collected for further problem analysis.

Some detailed information for lift equipment, mobile vehicles and crews could be achieved by using digital video cameras within the terminal. A lot of delays in terminal are caused by unexpected operation problems. Routine data such as text and numbers can hardly describe the problems clearly for analysis of these delays, but CCTV system could record the operation details. The video data have two useful applications: first, the manager in the control center could recognize and respond to a problem earlier; second, the problem data could be stored in a database; researchers could then analyze the problems, trying to recognize their similarities and make standards to solve them or to find and prevent the key problems that incur most delays.

4.3.2 Terminal Resource Reservation Module

Reservation systems have been used in many fields, such as airline ticketing, and they have been proved very effective for both plan optimization and cost saving. However, they have not been implemented in intermodal terminals.

In ITMIS, the central database includes information of planned and currently available storage spaces, lift equipment, track, yards, etc. This database could be connected to a terminal reservation system, which could allow transportation companies to make appointments to go through the terminal and to provide container and cargo details to intermodal terminal managers in advance. This information could be translated to terminal resource demand by some automatic software, and the reservation system would check previous reservations and scheduled plans to see if there could be enough resources to be allocated.

The reservation system could be helpful for carriers when they have some special need for lift or storage capacity. For example, if a train company is using double-stack technology or a shipping company is using megaship technology, they can provide such information through reservation system, so that intermodal terminal managers could plan to provide more cranes then normally needed; if some carrier is shipping hazardous materials, their reservation information could help terminal managers to schedule special equipment and storage spaces in advance. Thus the reservation system could transfer regular information and detailed requirements from carriers to intermodal terminals, so that terminal managers could make plans and schedules for resource allocation in advance based on such information. As a result, carriers would not need to wait for available equipment or spaces when they arrive at the terminal, and it could speed their transportation connections in intermodal terminals, and both time and cost are saved.

The reservation system could also help to improve resource allocation and crew assignment. Because reservations from carriers provide detailed data for demand of resources in the future, the information could be used for optimizing the resource allocation based on a fixed amount of lift equipment or storage spaces. The benefit would result in higher throughput for the terminal, higher utilization of terminal resources, and higher savings for terminal operation. The reservation system could also encourage carriers to book the resources earlier by offering a discount for, say, a 7-day advance reservation or a 14-day advance reservation. Thus terminal managers could collect enough information for their resource assignment optimization, and get more reliable result for actual operating plan.

In addition, terminal reservation system could be used to adjust the demand of terminal resources during peak workload periods. Terminal managers could set different prices for different times in a week and in a day based upon expected demand. For example, terminal managers could double the normal price for using one unit storage space on the peak day (which could comprise as much as 40% of total weekly demand in rail intermodal terminals [SMAI87]). Following this strategy, the customers would consider shipping their cargo to the intermodal terminal other than during a peak period in order to save some cost. If there is not enough demand during weekends for a terminal operated 7 days a week, combining the reservation system with a pricing strategy could increase weekend demand and smooth the resource allocation for the whole week.

Terminal reservation and pricing systems could improve the level of terminal customer service. For example, the time sensitivity of a particular shipment is hard to obtain in normal operating processes. However, this is an important factor for terminal operator in scheduling the resource assignments because they would like to build good customer relationships by meeting service requirements. The reservation system with peak pricing strategy could help to identify critical shipments, because customers could pay higher prices to obtain higher service levels.

4.3.3 Query Modules

The query modules could provide different graphical interfaces to customers and terminal managers for making queries.

Customers could log into the system to query many information related to services of the intermodal terminal. Based on current and historical data for the terminal and the network, ITMIS could provide customers estimated turn-around time and cost for specific cargo and vehicles, as well availability of different levels of services. For cargo owners, the system could provide current status of cargo inside the terminal, as well as their expected departure time and estimated destination arrival time. Based on real time position and speed of carriers, and the terminal operation situation, the system could provide the next pickup carrier precise estimates of cargo availability time as well as suggested best pick up time and place.

Terminal managers could view the current situation of the terminal through CCTV system, and identify the potential problems of the terminal operation. They could query the database to get equipment and crew information, then make plans based on this information. They could also make queries for particular shipments, and gather valuable information for customer relationship management.

4.3.4 Terminal Management Modules

A lot of information is in the central information system. It is hard for terminal manager to analyze so much information in a short time and make correct decisions. Thus, it is reasonable to connect the central information system to some automated software, which could process data and make recommendations for operation management.

Now let us see an example of recommendation from ITMIS. Historical video of accidents and problems are categorized and stored in CDs, and could be used for further analysis. If these data have been analyzed by data mining tools for loading delays, videos with similar problems or influence factors could be grouped together, and information of each video such as CD number, track number, and date could be stored in the database, and solutions for such problems are connected to the problem group as well. If some day there is an accident or a loading delay, ITMIS could search the database by similar features and find the special group with similar incidents, and provide terminal managers a recommended solution based upon what worked in the past. The managers could also choose to view historical video of similar problems.

The terminal management modules would handle vessel and rail planning, make equipment and facility scheduling and allocation, optimize the utilization of labor and storage spaces, and give recommendations to the terminal managers. Thus the terminal management modules could help to reduce the equipment idle time, improve terminal efficiency, productivity, and profitability, and improve customer service quality.

4.4 Summary

Intermodal Terminal Management Information System (ITMIS) is a system that could gather much useful information for terminal management. Its central database and several modules could help terminal managers to improve terminal operations and facilitate better information sharing among transportation partners. The central database system is the backbone of this information system. The data entry module, query module, and reservation module together provide carriers and terminal managers valuable information for planning and scheduling. The terminal management module, combined with automatic optimization software, helps terminal managers to optimize terminal operation.

Many communication technologies guarantee precise and accurate data entry and information sharing.

According to their current capabilities and characteristics, some IT technologies are illustrated to be used for several ITMIS modules, such as AEI, DGPS, digital CCTV, XML/EDI, and optical networks, and these capable technologies were shown in table 4.1.

The objective of this paper is to design the architecture of Intermodal Terminal Management Information System from a systems view, and to identify information technologies that are capable of supporting the performance requirements of ITMIS. The major concern here is the structure of information system, not the special characteristics of the technology. Because information technology is developing very fast, new technologies that are more effective for terminal information systems may appear in the next few years, and they may be used in ITMIS to supersede old technologies with similar functions. However, the basic idea of information sharing and the proposed structure of ITMIS should remain useful, since the operation of intermodal terminals and potential information flows are not expected to change dramatically over the next ten years.

Chapter 5 Cost and Benefit Analysis of ITMIS

In this chapter, I estimate the costs of implementing ITMIS for a hypothetical terminals, allocating the costs of different technologies. Second, I estimate the benefits of ITMIS on processes in terminals: gate operation, loading/unloading, resource allocation and storage, as well as container or trailer pickup/dropoff. These benefits are come mostly from information sharing among terminals and carriers and from using real time terminal information gathered by ITMIS. Third, I discuss the possibility of regional terminal cooperation, with examples for terminals belonging to the same company, for terminals belonging to different companies, and for marine terminals and rail intermodal terminals. Most quantitative analysis in this chapter is based on queuing theory and simple simulation models.

5.1 Cost Estimation for ITMIS

I will estimate costs for a hypothetical, large intermodal terminals with 400,000 containers/trailers annual throughput. According to the intermodal terminal database [ITD01], among 235 TOFC/COFC terminals in the United States, at least 90 had an annual lift capacity of at least 100,000, and 28 terminals had the capability of handling at least 250,000 trailers and containers annually. The four largest facilities in the United States had annual lift capacities of 700,000 to 900,000 trailers and containers for each terminal. Thus, the analysis addresses the larger but not the largest terminals. Assuming 250 workdays per year, the average daily workload is 1600 containers/trailers. Assuming the peak day has doubled throughput of the average daily load, there are 3200 containers/trailers throughput on peak days. In addition, I assume there are 1600 reservations for terminal resources daily, 6400 add/delete operations or modifications made to the central database, and 6400 queries daily. The intermodal terminal database indicates the average size of a TOFC/COFC facility was about 40 to 45 acres with approximately 700 parking spots, while the largest spanned over 250 acres and provided over 1000 parking spots. [ITD01] I assume the terminal size is about 150 acres.

Configuration of Servers and Workstations

To configure the database server, I need to estimate the requirements for the hard disk and memory. First let us estimate the hard disk requirement of the system. I assume the system will have information on all rail cars and containers that can be used in rail intermodal service. The RAILINC maintains Universal Machine Language Equipment Register (UMLER) with 1.7 million rail cars, as well as 4.5 million trailers and containers for the intermodal freight transportation in the United States. The size of one record in UMLER is at most 592 bytes. If all of the information is maintained for one intermodal terminal database, it is about 3.7GB. Suppose there are another 1GB information for other facilities and equipment within the terminal, 1GB for carriers and cargo, and 2GB for other information such as images and video clips. The total size of the database is about 7.7 GB. Multiply by 2 for indexes, temporary tables, etc, to get 15 GB for the database storage requirement.

Secondly, I will calculate the memory requirement. Suppose we need 64MB for the operating system, 64MB for SQL server, and 40 MB for ODBC. The 90/10 fractal rule for estimating memory requirements suggests adding 1% of database size (which is 150 MB) to the basic requirements, therefore a reasonable database memory size would be 512MB. [MITL01]

The Compaq website provides software (Compaq Proliant Sizer for Microsoft SQL Server 2000 Transaction Application) that will configure a database server based upon hard disk and memory requirements. For a system with 15 GB storage and 512 MB memory, Compaq's software recommends the Proliant ML530 computer with 1 CPU, 11 tape drives in RAID-1 configuration for high reliability and adequate performance. Tape drives include: 2 drives for the operating system and database system, etc.; 1 hot-pluggable drive to restore the machine quickly, which is usually used for the operating system and database software; 4 database drives; 2 application drives for images, videos, etc; 2 drives for the database log. They are all mirrored except the hot spare. The Compaq website estimates the price for this configuration to be about $20,000 for a database server. A backup server costs an additional $20,000.

According to the Compaq website, a basic web server for about $10,000 would be enough to handle the data load, while a high availability, fully configured server would cost about $75,000. I chose a middle range web server costing around $20,000 for ITMIS. Adding 20 workstations (with a unit cost of $500) inside the terminal for operation management, the total cost of the computer hardware is $70,000.

Network Technology

For the Local Area Network (LAN) inside the terminal area, we can choose FDDI because it is cheap, fast and stable. The upload and download speed of FDDI are both 100 Mbps, which is enough to handle the transactions, even including video (128 Kbps is a reasonable estimation because at least two 64 Kbps channels are needed for minimally acceptable videoconferencing) and images (with JPEG format, 100K of image size is clear enough for terminal information transfer). FDDI costs about $20,000 for the area of about 150 acres.

For accessing the Wide Area Network (WAN), I assume there are 1600 reservations, which is the average daily throughput. We know that 6400 add/delete/modification, and 6400 queries daily from the assumption. Given the number of working hours is eight per day, and the size of each transaction is 592 bytes, assuming the peak hour load is double the average load, the communication data flow is 4.7 Kbps. Adding the optional video of 128 Kbps and images of 2 Kbps bring the peak transmission requirement to about 135 Kbps. Thus we can use cable modems to access the network, since these provide 128 Kbps to 10 Mbps bandwidth. The initial cost for one cable modem is $100, and the monthly cost is $50. By using the same configuration for a backup system, for a ten-year period, the initial cost for the network is ($20000 + $100) × 2 = $40200, and the yearly cost is ($50 × 12) × 2 = $1200.

Digital CCTV System

With investigations in several websites for price of video cameras and camcorders, I think $5,000 per camera is a reasonable price. Suppose we install one video camera for every 10 acres inside the intermodal terminal, and three more cameras near the gate and tracks, there should be 18 cameras and the total cost is $90,000, with yearly maintenance cost of $2,000. A digital recorder that could be connected to 18 cameras costs about $10,000.

By using CD as the video storage media, and backup the video information everyday, two CD writers are required, which cost about $500. The CD media is about $0.10 ~$0.20 per piece, and the backup media cost is about $2~4 per day, $600~$1200 per year. So the total initial cost for CCTV system is $100,500, and the operating and maintenance cost is $3,200 per year.

AEI

According to Signal Computer Consultants website, there are two kinds of AEI system: one is an advanced system, which can be operated with temporary tags installed on vehicles going through the terminal, the other is a basic system, which can be operated only if with permanent tags installed on all equipment and vehicles. In the same website, there is a description for the advanced system: "The Advanced AEI System detects untagged vehicles by using a set of wheel detectors to determine that a vehicle passed the reader without a tag being read. This information is sent to the AEI Inventory Software that displays the untagged vehicle and assigns it a temporary initial (xxxx) and a number based on the date. The user can change the temporary initial and number to the actual." The cost is $26,000 for one advanced AEI system including software and hardware. One reader costs about $3,000, and a tag costs about $17 [AEIC01]. We could add 20 readers within the terminal for resource inventory control, so there is an additional cost of $60,000. Permanent tags are installed on terminal equipment, which include lift equipment and moving vehicles inside terminal. Assuming there are 200 pieces of equipment and moving vehicles inside terminal. Assuming there are 200 pieces of equipment in the terminal, the tags would cost $3,400. All rail cars have already been tagged, thus their cost do not need to be included. The trucks without tags will be assigned temporary ID by the software automatically, and they do not need to be considered for cost as well. Finally, 8,000 temporary tags are used for containers and trailers without tags (the weekly load of terminal throughput), which is about $136,000. Thus, the total initial cost of AEI technology is $225,400, and there may be $2,000 yearly maintenance cost.

An alternative method is to use the basic system, which needs to have permanent tags installed on all intermodal trailers and containers. Since it can only recognize the tagged vehicles and cargos. Signal Computer Consultants website describes the basic AEI system as follows: [AEIC01] "The Basic System consists of two AEI reader antennas (one on each side of the track) and a presence monitor which detects the presence of rail vehicles. This system sends AEI data to the AEI Inventory Software, which tracks the movement of tagged vehicles passing the reader location. This system will not detect untagged rail vehicles. Since less than 1% of the rail fleet does not have viable tags, many terminal operators feel this system is adequate to meet their needs." The basic system costs $12,000 [AEIC01]. However, a massive effort would need to be undertaken to put permanent tags on all intermodal equipment. Suppose there is a program to install tags and the cost is covered entirely by the railroad industry, with cost allocated according to volume handled at major terminals. According to the intermodal terminal database, there are 235 TOFC/COFC terminals in the United States, at least 90 of these TOFC/COFC terminals had an annual throughput capacity of at least 100,000, and 28 terminals had the capability of handling at least 250,000 trailers and containers annually. Based on these numbers, a terminal with 400,000 annual throughput would be required to cover about 5% of investment in permanent AEI tags. Since UMLER includes 4.5 million intermodal trailers and containers, the terminal would be responsible for 225,000 tags at a cost of $3.825 million. This is a very large expense, so it is reasonable to assume the advanced AEI system will be used in ITMIS, with temporary tags for containers and trailers that go through the terminal.

DGPS

We assume that the carriers have DGPS receivers to keep track of the locations and speed of trains, trucks, and ships. We also assume that the carriers would share information with the terminal based on an information-sharing contract, so that the terminal would not have to cover the cost of DGPS equipment. The transmission data flow has already been considered in the web server configuration and selection of network technology.

Software

Special software modifications may be needed for each intermodal terminal for their specific characteristics and resource inventories, so that there will be cost for software development and data collection. We may use SPARCS/EXPRESS as the basic module and add some control modules for rail and highway intermodal requirements, as well as the equipment and facilities in the terminal. Considering future development, the system requirements investigation, data collection, software license and development cost is estimated at $100,000 initially and $2,000 maintenance yearly.

Summary of Costs

Table 5.1 summarizes initial cost and yearly maintenance cost for components we have discussed and adds labor training cost as well as the salary for a system administrator. Given the assumption of 10% of APR and a 10-year system life period. Table 5.1 also shows the equivalent annual cost and present value of investment. In sum, the initial cost of the ITMIS is about $560,000, and the yearly maintenance cost is about $70,000. With 10% APR, the equivalent annual cost in a 10-year period for the ITMIS would be $160,000 per year, and the present value of total investment would be about $1 million.

To put this cost into perspective, we can compare it to the cost of capacity. Drewry Shipping Consultants Ltd estimates an investment cost of $18.5 million for each 100,000

TEU of new capacity, including both civil works and equipment. [WCTG98] Hence, the cost of the ITMIS is equivalent to the infrastructure investment for an extra 5300 TEU of new capacity per year. Thus, if the ITMIS increases terminal capacity by more than 1.5%, then it will be more efficient to invest in ITMIS than in adding infrastructure.

Components	Initial Cost	Yearly Maint	Annual Cost	Present Value
Computer Hardware	$70,000	$2,000	$13,000	$82,000
Network	$40,200	$1,200	$8,000	$48,000
CCTV	$100,500	$3,200	$20,000	$120,000
AEI	$225,400	$2,000	$39,000	$238,000
Software	$100,000	$2,000	$18,000	$112,000
Labor	$20,000	$60,000	$63,000	$389,000
Total	$556,100	$70,400	$161,000	$989,000

Table 5.1 ITMIS Costs Summary

5.2 Benefits from Information Sharing Among Terminals and Carriers

Gambardella et al stated, “Storing containers on the yard, allocating resources in the terminal, and scheduling vessel loading and unloading operations are major problems in an intermodal container terminal”. [SPIC98] I will discuss the “additional” benefits of ITMIS for gate operations, lifting process, storage, as well as resource allocation. The “additional” benefits of ITMIS come from information sharing and from new information technology components in terminals, but do not include benefits from technologies already commonly used in intermodal terminals.

Real time information gathered in ITMIS can be used for demand forecasting, resource allocation planning, and operation simulation. Furthermore, terminal operations including storage, lifting, and pickup/dropoff can be optimized by using automatic software and Operations Research techniques. Zaffalon et al said in their paper [RASO99] “Operations Research techniques have proven to be a reliable and convenient tool to support the decision-makers in the daily operations in many cases”.

5.2.1 Gate Operation

The gate operation, which involves security check, equipment interchange, liability transfer, and cargo information processing, is an integral part of the whole intermodal terminal system. Its productivity has a direct impact on the overall terminal capacity as well as on truckers' profitability. Low throughput would cause inefficient utilization of terminal equipment and storage spaces, and congestion at the gate may increase the truckers' turnaround time and reduce the number of runs they can make per day.

General Gate Operation

Before the ITMIS application, if there is no pre-gate to direct the trucks, the terminal gate works as m G/G/1 systems (general inter-arrivals distribution, general service time distribution, one server), where m is the number of lanes at the gate. Because the truck can hardly change to another lane when it is in the middle of a queue, each lane works like a G/G/1 system. If there is a pre-gate in the terminal, the gate works more like a G/G/m system (general inter-arrivals distribution, general service time distribution, one server). Because on shipments is obtained before they reach the gate, trucks can be directed to the "right" gate according to this information. Trucks can be sent to any of the m lanes at the gate when they are waiting in the queue at the pre-gate.

To simplify the calculation, I consider the case without pre-gate, and use the formula of heavy traffic approximation for the G/G/1 system [DNSE92]. The average waiting time in the queue satisfies $W \leq \lambda (\sigma_a^2+\sigma_b^2) / (2(1-\rho))$, where λ is the average arrival rate, ρ is the utilization factor λ / μ, and $1/\mu$ is the average service time, σ_a^2 is the variance of the inter-arrival times, and σ_b^2 is the variance of the service times. The variance of inter-arrival times before ITMIS is bigger than that of inter-arrival times after ITMIS with the same average arrival rate, because most of the trucks may arrive during the peak hours, and their arrivals are random since they are not adjusted by advanced information system. After ITMIS application, we can arrange the truck arrivals by using terminal resource reservation system. The variance of time between truck arrivals would then be reduced greatly; although it may not be uniform distributed, it will be very similar to a Poisson distribution, so the system can be described accurately by an M/M/n queue. The variance of the service times before ITMIS is also bigger than that of service times after ITMIS, because the accurate information gathered from AEI and video cameras, as well as the XML/EDI information exchange would guarantee steadier automatic gate processing. Assuming the system utilization factor ρ does not change, the upper bound of waiting time for each truck after ITMIS would be less than what we get before ITMIS application, and the average length of queue $N_q = \lambda W$ becomes less after ITMIS as well. For example, if both of the variances are cut by 25%, the waiting time will become 75% of the waiting time before ITMIS.

Science Applications International Corporation's (SAIC) installed an automated gate system, using AEI and video cameras, for Union Pacific Railroad's Oakland Facility. Tom Milner, the SAIC program manager, said, "More than 60 percent of the gate transactions are processed automatically in 30 seconds or less without the intervention of a gate clerk." [SAIC99] According to a study by Vickerman-Zacary-Miller, the average total gate processing time is 2 minutes by using existing AEI tags. [AEII94] Because ITMIS also uses AEI and video cameras at the gate, I assume the average gate service time is similar to SAIC's estimation; to be conservative, I assume it is 0.5 minutes. The "total processing time" of 2 minutes given by Vickerman-Zacary-Miller includes queue time and service time. Thus 2 minutes of total processing time minus 0.5 minute of service time equals an average queue time of 1.5 minutes. Considering 25% of waiting time savings discussed in the last paragraph, the queue time savings could be 0.375 minute per transaction. With 400,000 transactions per year as I assumed in the cost estimation section, the time saved can be 2500 hours annually. Since the trucker's opportunity cost (including driver wage, insurance, wear-and-tear, and other considerable cost) is estimated at \$50 per hour [ITGO01], we use a relatively conservative trucker cost of \$30 per hour, the total annual savings for all truckers going through this terminal gate could be \$75,000.

Peak Period Gate Operation

Yahalom, etc. observed a typical marine container terminal gate in 1998, [ITGO01] and found that there are significantly peak days and peak hours in the gate operation. They claimed, "due to ship sailing schedule, the busiest days of the week are normally Fridays and Mondays". According to their observation record, the number of trucks waiting in the queuing area and streets is varying from hour to hour, and early in the morning (7-9am) usually is the peak period. To calculate capacity of the intermodal terminal, we need to consider the peak arrival period separately from the non-peak period. A possible solution to the peak period capacity is to adjust the demand of gate resources. i.e. adjust the arrival rate between peak period and non-peak period, so that the system utilization rate is kept at some level without big variance. That is why ITMIS suggests using reservation/bidding systems to adjust the demand. As a result, the average arrival rate λ in peak hours would decrease. By using the same G/G/1 formula stated above, $W \leq \lambda (\sigma_a^2+\sigma_b^2) / (2(1-\rho))$, if the peak arrival rate λ is decreased to 80% of original rate, the upper bound of waiting time in the queue during peak period would be decreased by another 20% in addition to the decrease caused by time variance change, and the total saving of waiting time during peak period is 1-75%*80%= 40%.

Now let us calculate the maximum throughput at terminal gate. In peak period, the departure rate is lower than arrival rate, and the system is not at steady state. So I make assumptions that there are enough arrivals to keep at least one truck in the queue and enough spaces to hold the queue so that arriving trucks will not leave when seeing a long queue. Thus, during the peak period, the average number of transactions per lane per hour will only depend on the service time (0.5 minute) at the gate, and it is at most 60/0.5 = 120 transactions. Suppose the terminal gate is operated 8 hours per day, 5 days per week, the annual potential maximum throughput of a lane at the gate is 240,000 vehicles per year (250 days). AEI and video systems can help improve efficiency of the gate, although this may not have an effect on terminal capacity. Because the number of lanes is not very hard and expensive to increase, the gate throughput should not be the bottleneck of the terminal capacity.

5.2.2 Lifting Queue Analysis

Kelly and Steenburg claimed in 1996 that “Compared with gate operations, inefficiency in crane operations creates more disabling characteristics for an intermodal facility.” [ELS96] In the following, I will discuss the influences on loading and unloading by ITMIS.

As discussed in the gate operation, the inter-arrival time of trucks can be assume to be a Poisson distribution because of the use of a reservation system. Before ITMIS, I assume the operation of cranes as m M/M/1 system, i.e. each crane works independently. After ITMIS, I assume the operation of cranes as an integrated M/M/m system, i.e. the cranes cooperate with each other through the real time inventory control and information communication; containers in the terminal could be scheduled almost “real time” according to crane inventory, plan and performance. It should seem as if all containers are in one queue to wait for available service from a crane.

I used productivity figures from Sea-Land and Maersk to estimate the number of cranes required in the “test” terminal. The research of Sea-Land Services, Inc. found that the average crane productivity at their marine yards is about 25 lifts every hour, the service time of a crane operating at full capacity is about 1 minute per lift, and cranes can achieve operations of up to 45 to 50 lifts each hour [ELS96]. Thus, actual productivity is likely well below achievable productivity at major intermodal facilities, which may reflect idle time of cranes while appropriate containers are being located and moved before loading. Maersk Pacific designed its intermodal terminal at Long Beach in California with expectation of eventually reaching 250,000 vessel moves per year. This terminal comprises three vessel berths and six quay cranes. [AIPC96] With 400,000 containers of throughput per year for the test terminal, the number of daily lifts for loading and unloading is 1600 containers. Based on these numbers, I assume there are 8 cranes in the sample terminal, the normal arrival rate at one crane is 25 per hour, and the peak arrival rate at one crane is 50 per hour.

In order to compare the crane performance, table 5.2 uses m M/M/1 system model for the case before ITMIS, and uses an M/M/m system model for the case after ITMIS. The arrival rate of 200 per hour represents the average workload, which equals 25 lifts per hour per crane; the arrival rate of 400 per hour represents the peak workload, which equals 50 lifts per hour per crane. Table 5.2 shows the calculated result of expected waiting time in the queue and in the system, as well as the expected number of containers in the queue and in the whole system. Before ITMIS, the waiting time in the queue is 43 seconds at normal working load (200 containers/hour); it is 5 minutes during peak arrival period (400 containers/hour). The queue length for each crane is 0~1 container during non-peak period, and it is 4~5 containers during peak period. Throughout the whole terminal, there are about 33 containers waiting in line for service during peak period. After ITMIS application, the queue time is almost zero and there is almost no containers waiting in the queue during non-peak period. The waiting time for service is only 24 seconds in peak period, and there are only 2~3 containers waiting in the whole terminal, which decreased the queue length by about 90%. The time in the system saved by ITMIS during peak period is expected to be about (6-1.4)/6 = 77%.

	m M/M/1 systems (Before ITMIS)			One M/M/m system (After ITMIS)		
# of Servers (m)	8	8	8	8	8	8
Arrival Rate (# / hour)	200	300	400	200	300	400
Service Time (min)	1	1	1	1	1	1
Expected Time in the queue	0.71	1.67	5.00	0.00	0.06	0.40
Expected Time in System	1.71	2.67	6.00	1.00	1.06	1.40
Expected # in the queue	2.38	8.33	33.33	0.02	0.28	2.66
Expected # in System	5.71	13.33	40.00	3.35	5.28	9.33
Probability of Waiting	0.42	0.63	0.83	-	-	-

Table 5.2 Lifting Queue Analysis

Since the performance of lifting operation could be so good by applying ITMIS, the terminal lifting capacity is expected to be increased as well. Table 5.3 shows the capacity increase from ITMIS by changing arrival rate in M/M/m system while keeping the number of servers and service time unchanged. I estimated the increase in capacity by finding the arrival rate with almost the same performance as that in the M/M/1 system, i.e. similar queue length and queue time. We can see some very attractive results from this table: the performance of one M/M/8 system with 468 per hour arrival rate is almost equal to that of eight M/M/1 systems with 400 hourly arrivals; the performance of one M/M/9 system with 528 per hour arrival rate is almost equal to that of nine M/M/1 systems with 450 hourly arrivals. This suggests that the same equipment can increase the peak capacity as much as 17% if applying ITMIS. If the terminal chose to buy a new crane to increase the lifting capacity instead of using ITMIS to allow better coordination of lift operations, it could cost $6.5 million for a big crane used in ports according to investment forecast by Drewry Shipping Consultants Ltd [WCTG98]. It could cost $0.5 ~$1 million for a smaller crane used in rail terminals. One crane can increase the capacity by at most 50 lifts per hour, which is a 12.5% increase to the original capacity, but it is not as good as the system benefit achieved by ITMIS--68 lifts increase per hour which is 17% increase to the original capacity. The calculation of this table also shows that the benefit from ITMIS is a little greater for large-scale terminals compared to small terminals--lifting capacity increase could be 15% for 4 cranes and 18% for 10 cranes.

	m M/M/1 systems (Before ITMIS)					One M/M/m system (After ITMIS)				
# of Servers (m)	4	6	8	9	10	4	6	8	9	10
Arrival Rate (# / hour)	200	300	400	450	500	229	349	468	528	588
Service Time (min)	1	1	1	1	1	1	1	1	1	1
Expected Time in the queue	5.0	5.0	5.0	5.0	5.0	4.9	5.0	4.6	4.6	4.6
Expected Time in System	6.0	6.0	6.0	6.0	6.0	5.9	6.0	5.6	5.6	5.6
Expected # in the queue	16.7	25.0	33.3	37.5	41.7	18.7	29.1	35.9	40.7	45.5
Expected # in System	20.0	30.0	40.0	45.0	50.0	22.6	34.9	43.7	49.5	55.3
Max Throughput Increase	-	-	-	-	-	15%	16%	17%	17%	18%

Table 5.3 Lifting Capacity Analysis

There is evidence that more effective utilization has a large payoff for terminal operations. Sea-Land Services, Inc. found that “With an increase of just 1 lift per hour, operators save $250,000 to $1 million each year” depending on the size of facility [ELS96]. The bigger the terminal, the higher the saving per lift. With automatic optimization procedure for resource allocation, Zaffalon et al shows that it is possible to improve the yard crane performances by as much as 30% [RASO98]. Although they stated that they "have tuned and validated our model using real world data", I would like to use a conservative estimate of 10% for the performance benefit. Assuming such benefit is phased in uniformly over 10 years, the crane lifts per hour could increase about 25*10%/10 = 0.25 per year. For the 10-year period, the average benefit would be about 5%, or 1.25 lifts/year. The average annual savings would therefore be $300,000 ~$1.25 million, depending on the type of lift equipment.

5.2.3 Resource Allocation

Resource allocation is another excellent application area of ITMIS. The information gathered in ITMIS can be used to forecast peak demand for some special equipment. If peak demand exceeds capacity, terminal managers could rent equipment from other terminals, use a reservation system and pricing strategy to reduce peak demand, or change resource allocation to deal with the problem.

Resource optimization can also help terminal managers to get better plans for operations. For example, terminal managers could arrange similar operations together, thus saving the moving time of equipment and increasing equipment utilization. If it is rented equipment, money and labor cost can both be saved by optimization of resource allocation.

Zaffalon et al demonstrated how a model could improve resource allocation policies based on network flow analysis. He found the best combination of quay cranes and yard cranes to minimize operating cost while balancing the flow of containers to and from the ship over a number of shifts that is limited by a deadline. The model can provide an approximately optimal solution of resource allocation, and the solution can generally be found by a computer in few minutes. The optimization could be very effective: "Our optimization procedure is able to improve the yard crane performances of about 31%." said Zaffalon et al [RASO98]. If terminal managers use similar optimization models in terminal control module of ITMIS to make resource allocation, then other parts of ITMIS can provide important real time information of resource inventories and carrier reservation schedules for input of models, thus it becomes a more efficient system for decision making.

5.2.4 Storage and Pickup/Dropoff

Limited storage space is usually a bottleneck in the terminal operation. Because the intermodal terminals are usually located close to the urban area, it is hard and expensive to expand the storage space in horizontal level. According to Drewry Shipping Consultants Ltd estimates [WCTG98], the construction investment of 100-acre container yard is about $638,000. Some terminals are stacking containers so that they can use the vertical space as much as possible. But the resulting problem is that it is very hard to move the containers in the lower level, and more lifts are needed to complete the move. This is not efficient for the lifting equipment, which is expensive and also may be reaching capacity. In the ITMIS system, all the dimensions, weight, status, arrival and departure information for each container are stored in the central database, and their real time location are updated by AEI scanners and temporary tags on containers inside the terminal. This kind of information is helpful for optimizing the stacking of containers, as well as efficient moving of containers. For example, containers arriving earlier and departing later from the terminal should be stored at lower levels than the containers arriving later and departing earlier, so that there will be fewer lifts for moving lower level container. Another simple example is to try to stack together containers that will be loaded to the same departure train.

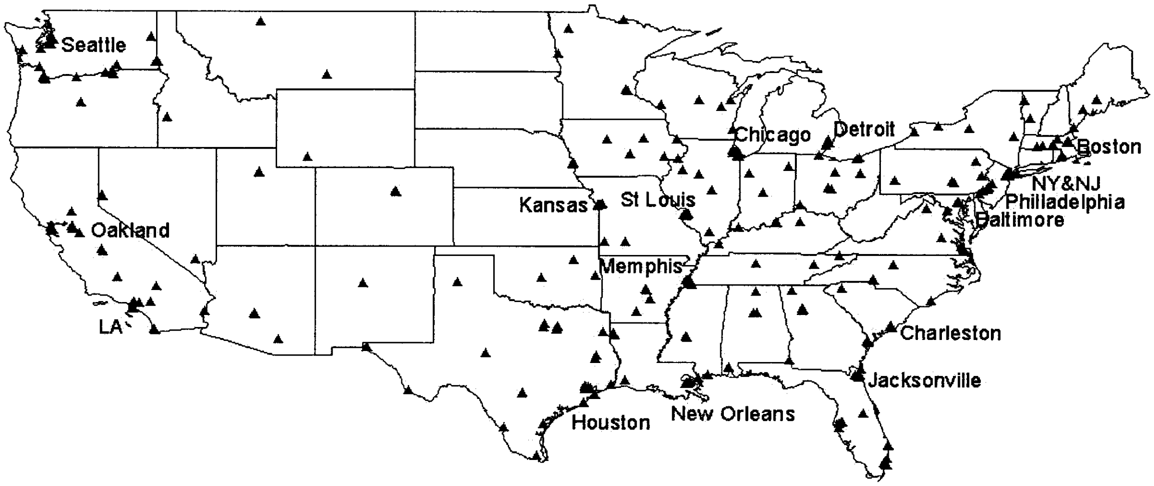
Another method to save limited storage space is “just-in-time” pickup and dropoff. The real time information system in ITMIS provides precise arrival time and departure time, and the terminal could share information with trucking companies by XML/EDI data exchange. Thus the strategy of “just-in-time” pickup or dropoff becomes more feasible with this accurate information. The trucks could be driven directly to the loading yard, and containers are lifted onto the train from the truck. Or the truck could come to the terminal as soon as the train arrives and completes the inbound inspection, and the truck is driven directly to an unloading yard to pick up the container from the train. This procedure makes the storage of container within terminal becomes unnecessary or shorten the storage period in terminal. If the “just-in-time” strategy could be applied to 30% containers that go through the terminal, it is possible that ITMIS could help increase the terminal storage capacity by 10%.

To pick up a container in a storage slot often needs more time than to drop off a container, this is because the procedure of finding the container is much harder than finding an empty storage slot. With the automatic equipment identification in ITMIS, the pickup procedure could be as easy as a dropoff. All containers are attached a temporary tag and the scanners are all over the terminal, so that locating a container and updating the terminal inventory become very fast.

5.3 Benefits from Information Sharing among Regional Terminals

5.3.1 Possibility of Cooperation

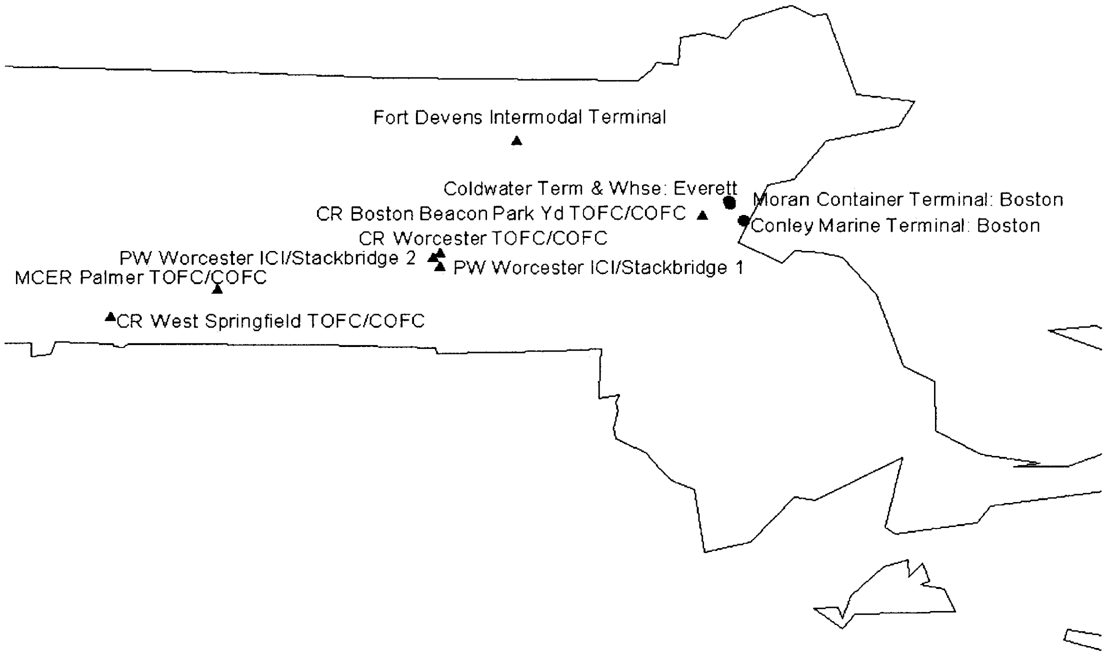
As shown in figure 5.1, there are clear groups of regional terminals because they are very close to each other, especially in metropolitan areas such as Seattle and Chicago. If we can improve the communication among these local groups of terminals, it should be possible to allocate the workload more effectively.



Source: Intermodal Terminal Database, 1998

Figure 5.1 Intermodal Terminals Handling Containerized Cargo in U.S.

In the following figure 5.2, I show that 10 intermodal terminals handle containerized cargo in Massachusetts. We can see there are two regional terminal groups, in Boston and in Worcester. The Boston group includes three terminals within the range of about 15 square miles: Moran container terminal and Conley marine terminal are container ports; Beacon Park Yard terminal is a rail/highway terminal. The Worcester group includes three rail/highway terminals within a range of about 10 square miles.



Source: Intermodal Terminal Database, 1998

Figure 5.2 Massachusetts Intermodal Container Terminals

Table 5.4 shows the statistics result for fifteen groups of regional terminals: number of terminals in the group, average size of rail terminals in the group, the region size (distance from east to west, and distance from north to south), and the area of region. In Seattle, 14 intermodal terminals are within the area of 82.8 square miles. It should not be too difficult to connect the management information systems of these terminals with a local area network serving each metropolitan area. Thus the facilities and equipment of multiple terminals could conceivably be managed together, with appropriate contracts, to achieve system optimization. For example, if a carrier is redirected from the north to the south of a terminal region, it could take a few more minutes to travel, but perhaps save time overall by avoiding a congested terminal. If carriers can access the inquiry module of terminal information system, they can know the redirection plan in advance and drive to the new destination terminal to help reduce congestion or storage space limit in the scheduled terminal. In Los Angels, 17 terminals are distributed in the small area, which is 6.7 miles from east to west, and only 2.9 miles from north to south. In Chicago, 22 intermodal terminals are located together in the square area of 26 miles times 26 miles. In New York and New Jersey, 19 terminals are together in the area of 210 square miles. If the terminals in the same regional area all cooperated with each other very well, the total performance of the regional intermodal transportation would be highly improved.

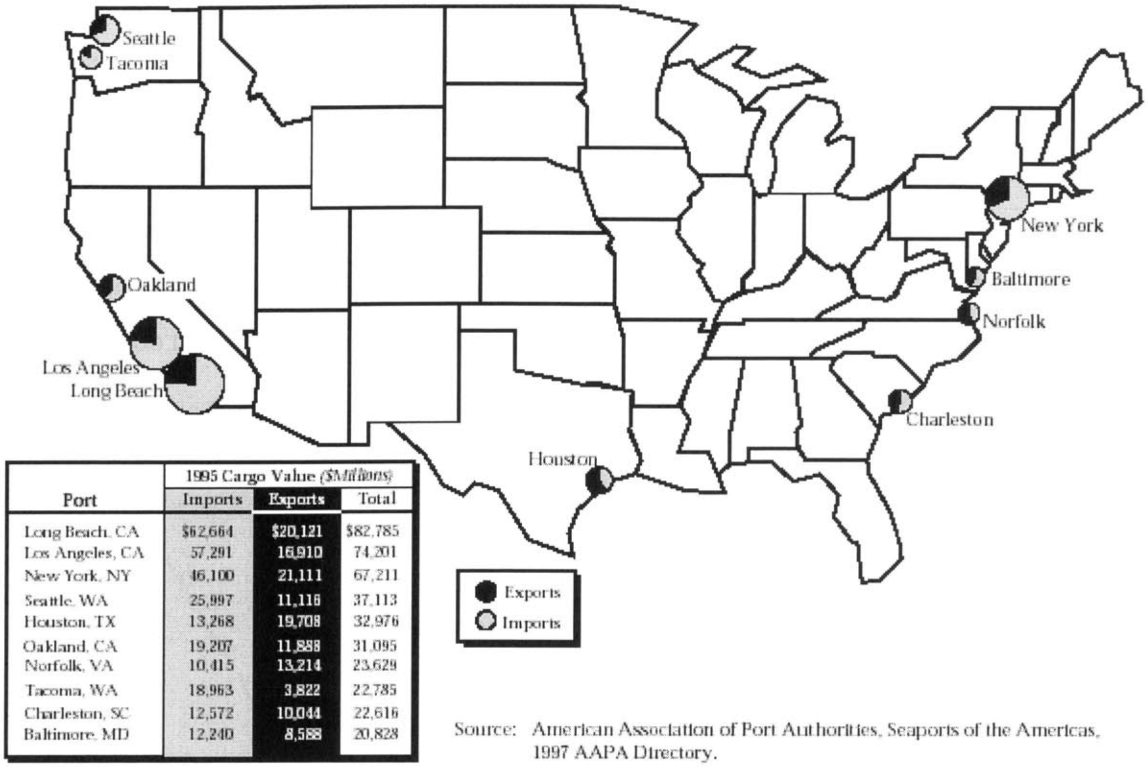
Place	# of Terminals	Ave Size (acres) (Rail Terminal)	East-West (mile)	North-South (mile)	Area (mile^2)
Seattle	14	97	7.2	11.5	82.8
Oakland	12	-	5.6	2.4	13.4
Los Angels	17	-	6.7	2.9	19.4
Kansas City	7	84	16.6	7.0	116.2
St. Louis	7	109	15.2	13.0	197.6
Memphis	7	98	13.2	10.4	137.3
Houston	5	190	4.5	12.6	56.7
New Orleans	12	52	14.8	7.0	103.6
Jacksonville	6	-	15.6	10.5	163.8
Charleston	5	-	8.1	7.5	60.8
Baltimore	7	91	6.4	4.9	31.4
Philadelphia	8	-	10.7	9.6	102.7
NY&NJ	19	-	13.6	15.5	210.8
Boston	4	-	7.5	3.6	27.0
Chicago	22	972	26.3	26.2	689.1

Source: Intermodal Terminal Database, 1998

Table 5.4 Regional Terminal Statistics in the United States

The problem is that these terminals may belong to different companies or organizations, or they may not have effective methods to share their information concerning the current situation. For example, there may be a terminal (say, terminal A) that is reaching its capacity so that it has to supply limited service, while another terminal (say, terminal B) not far away may be underutilized. A carrier C may plan to go through terminal A, even if the cargo can be handled by terminal B. If the manager of terminal A does not know there is another terminal that can help them out of the congestion problem, or if he cannot inform terminal B to help because they have not built a partnership, then he has to accept traffic from carrier C which makes congestion even worse, or require carrier C to choose a later time drop off the load. Either choice hurts customer service. Terminal B is wasting its resources and experiencing low facility and equipment utilization, so that its operation is not efficient because of insufficient demand. Carrier C has to accept the limited service from terminal A because it does not have partnership with terminal B or does not know the relative situation of terminal A and B. The congestion in terminal A and the limited service for carrier C may influence the other components of the intermodal network, as well as the level of service for the end customers. We therefore propose an integrated structure for cooperation among intermodal terminals.

From the above example, we know that the information sharing and partnership between terminals and among terminals and carriers are very important. Figure 5.3 shows that the regional areas with big terminal groups are usually the places with the largest ports in the United States. Thus the optimal operation in regional terminals means a lot for the total exports and imports of the whole country. If the delay and congestion in these regional areas can be mitigated, it would be very helpful for the freight transportation involved in imports and exports.



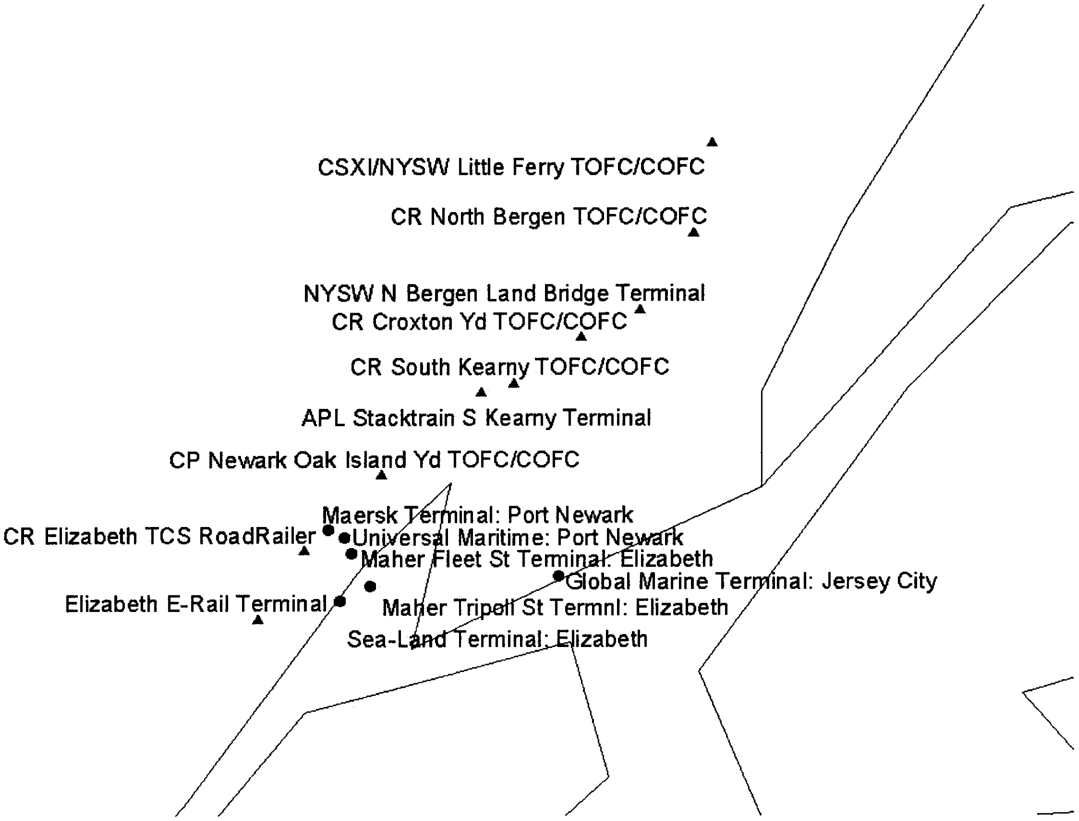
Port	1995 Cargo Value *($Millions)*		
	Imports	Exports	Total
Long Beach, CA	$62,664	$20,121	$82,785
Los Angeles, CA	57,291	16,910	74,201
New York, NY	46,100	21,111	67,211
Seattle, WA	25,997	11,116	37,113
Houston, TX	13,268	19,708	32,976
Oakland, CA	19,207	11,888	31,095
Norfolk, VA	10,415	13,214	23,629
Tacoma, WA	18,963	3,822	22,785
Charleston, SC	12,572	10,044	22,616
Baltimore, MD	12,240	8,588	20,828

Source: American Association of Port Authorities, Seaports of the Americas, 1997 AAPA Directory.

Figure 5.3 U.S. Port Rankings by Total Cargo Value

5.3.2 Sample Applications of ITMIS in Regional Terminal Cooperation

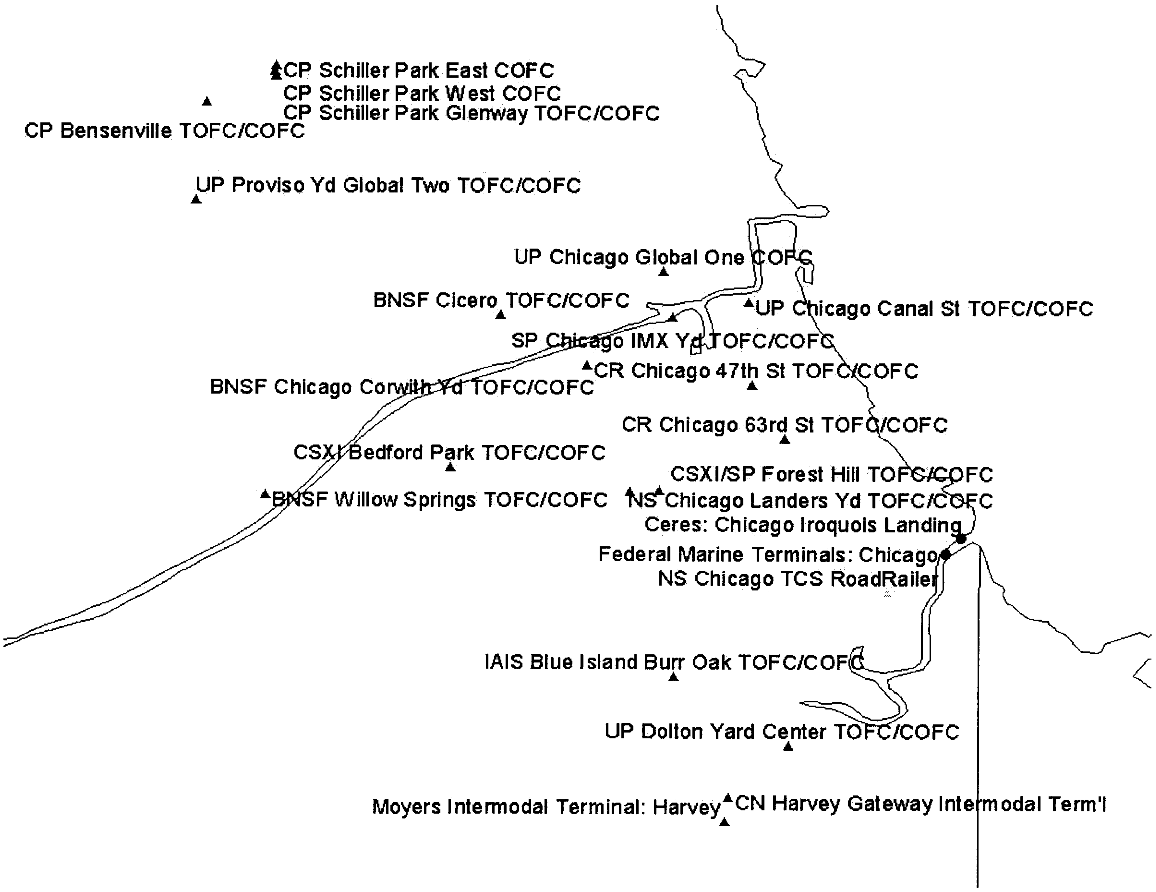
Now let us consider some examples for analyzing the possibility of benefits gained by information sharing among terminals. The first possible application of ITMIS is that for rail terminals owned by the same company, the information system can allow these terminals to operate together as an integrated virtual terminal; the shared information would be helpful to solve the problems of capacity constraint. The following figures 5.4 and 5.5 show the New York & New Jersey intermodal terminals and the Chicago intermodal terminals that handle containerized cargo. The highway-rail terminals are indicated with triangle symbols, and the highway-water terminals are indicated with round symbols. There are four former Consolidated Rail TOFC/COFC terminals in New Jersey: North Bergen, Croxton, South Keamy and Elizabeth TCS RoadRailer. These terminals are not far away from each other (less than 12 miles) and truckers can travel from one terminal to another in about 15 minutes, so that the redirection of cargo or movement of equipment among terminals is feasible and potentially acceptable by both terminal operators and truckers. The connection of ITMIS for these four terminals would make them virtually one big terminal—they could share drayman among terminals; they could make full use of spare resources such as lifting equipment and storage spaces; when one terminal is going to reach its capacity limit, other terminals in this region could help it to handle the overflow cargo; if there is some incident limiting the access to one terminal, or if there is some safety accident inside a terminal, then draymen could be informed to redirect the cargo to other terminals.



Source: Intermodal Terminal Database, 1998

Figure 5.4 New York & New Jersey Intermodal Container Terminals

A similar example can be found in Chicago area. The four Union Pacific terminals are away from each other by no more than 15 miles, which may take 20 minutes to travel. Chicago Global One and Chicago Canal St terminals are within 2.5 miles so that they could share the equipment and vehicles easily. Various strategies can be developed for sharing the work among these terminals. With ITMIS, more flexible and more effective strategies are possible. Through information sharing, the terminals within the same region could know their own demand and capacity as well as their neighbors' demand and capacity, so that the further cooperation among these terminals could possibly make a better regional system optimization. It could make full usage of lifting capacity and track capacity, provide spare storage space to other UP terminals, reduce the delay due to capacity limit or accidents, and improve the customer service level for the whole regional system. Similar cooperation can be applied to four CP rail terminals in Chicago area, as well as the BNSF, NS, and CSXT rail terminals. After cooperation based on information sharing from ITMIS, the optimization of storage spaces and other resource allocation could be made in a more integrated system, achieving better results for the whole system than the sub-optimal solutions made if each terminal acts independently.



Source: Intermodal Terminal Database, 1998

Figure 5.5 Chicago Intermodal Container Terminals

Secondly, for regional rail terminals owned by different transportation companies and working on the same modes of transportation, there may be some impedance to prevent them from cooperating, because the companies are competing in the same market, and any of them would like to increase market share and entice more customers. However, there is still some chance to build relationships among these companies and gain some benefits from ITMIS. For example, if one terminal is reaching its capacity, and it is hard to increase the capacity by infrastructure soon, the owner of this terminal would consider "subletting" some cargo demand to other terminals. If there is no terminal owned by the same company in the same region (e.g. IAIS Blue Island Burr Oak TOFC/COFC in Chicago), or all terminals owned by the same company in this region are reaching their capacity, the company will consider terminals owned by other companies.

In addition, the delay inside the terminal may cause congestion to the highway system near the terminal and influence highway delays at railroad crossings. As a result, it would make highway congestion and air quality worse in the city, so that regional transportation organizations might possibly ask the terminals to work together although they are not owned by the same company. Possible cooperation may happen among nine rail container terminals in NY& NJ, or among twenty rail container terminals in Chicago area. By using ITMIS, the information of real time cargo movement and reservation could be shared among different companies, so that they could improve their cooperation, achieve better operating schedules, and manage to achieve higher utilization of equipment and other resources.

Third, the application of ITMIS could help to improve port performance through information sharing. Because many ports are mainly handling containerized cargo, it would be possible to balance the container load among the highway-water terminals so that they could use their cranes, storage yards and other equipment or facilities more efficiently. For example, since the two Maher terminals shown in figure 5.4 are owned by the same company, they are cooperating in some level currently, and ITMIS could possibly help them to coordinate better through information sharing. While the good relationship is built with appropriate contract among different companies in the same region, they can cooperate well and optimize the cargo handling in the regional system. This is more likely to happen in the region with capacity tension or under the influence of a regional transportation organization such as Port Authority of NY&NJ. The terminals in the same regional organization could work together to achieve the best performance and provide good customer service to carriers and shippers. In NY&NJ region, it may be possible for the six marine terminals to cooperate better. For example, the number of containers in one ship could be very large since some marine companies are using megaship strategy; the arrival of one ship may cause one terminal to be very busy and reach its capacity limit, and may be hard to handle more cargo. In addition, the arrival of ships may not stick to their schedule because of unexpected weather conditions or other factors. The satellite communication system could locate ships and estimate their speed, so that help to predict the exact arrival time, and ITMIS could get this information from carriers. If two ships arrive at terminal A at almost the same time, it may lead to congestion, and the central management information system could ask another terminal in this regional group to prepare required resources: either transfer some resources to terminal A, or redirect the ship to the new terminal for unloading. Thus the ITMIS could help to decrease the terminal congestion, improve the resource utilization, and provide better service to the carriers.

Fourth, there is possible application of ITMIS to support more on-dock rail service to ports, if railroad and marine terminals want to share the workload and storage spaces. With ITMIS, the information gathered from marine terminals, rail terminals, ships and trains could be shared and queried sooner and more easily, allowing better coordination and efficient connections among rail and marine terminals. For example, in the port of NY&NJ, there are six marine terminals and nine rail/highway terminals within about 100 square miles. The workload of containers handled in the marine terminals is usually more variable than that in rail terminals because of peak loads related to arrivals of large ships. If the existing rail between ports and rail terminals could be used for connection of these terminals, part of the congestion problems in marine terminals could be resolved by shifting the heavy storage load to rail terminals. By using "just-in-time" trucker pickup strategy, the capacity limit of the storage space in rail terminals would not be a big problem either. Based on cooperation of rail and marine terminals, ITMIS could help the communication and information sharing between rail and marine terminal groups, so that the rail terminals could be informed in advance to prepare lifting equipment and storage spaces. Thus ITMIS could help to build seamless connection between water and rail instead of using highway as bridges to the two systems, and finally improve the performance of ports and regional intermodal transportation system.

Decreased congestion inside terminals can be beneficial to the whole intermodal network and to metropolitan transportation. Direct connections between rail and marine terminals would reduce highway traffic and help to resolve congestion in the highway network. As a bonus benefit, air quality of the region could be improved by reducing truck transportation to the ports, because less pollution is generated by rail transportation than by truck transportation. The cooperation among several terminals would save operating cost of terminals, reduce land requirements, and ensure better service to carriers and end customers.

5.3.3 Quantitative Analysis of Regional Terminal Cooperation

I have discussed the possibility of regional terminal cooperation to show the qualitative benefits of ITMIS. In this section, I will give some quantitative analysis for of the benefits that could be gained from sharing information from ITMIS.

Before Regional terminal cooperation, I approximate the operation of one intermodal terminal that is independent of other terminals and works as an M/M/m system, because the reservation system, real time information and terminal operation optimization can make the inter-arrival times and the service time as Exponential distribution, thus make the Poisson arrivals and departure. By using ITMIS for many intermodal terminals in the same region, the information sharing among regional terminals can connect them together and made them virtually one big terminal, then the system would be like a M/M/N (N is the sum of servers for all terminal in the group, $N=m_1 + m_2 +\ldots+m_k$ if there are k terminal cooperated). The new system is much more robust to the variance of demand and the length of queue, waiting time of trucks can also be reduced. This queuing model is similar either at terminal gate operation or lifting operation. Because the lifting capacity is a bigger concern than gate throughput, in the following table, I use lift queue as an example to illustrate the benefit of regional terminal cooperation.

Table 5.5 shows the expected queuing characteristics for terminals (or coordinated groups of terminals) having from 2 to 48 servers (i.e. cranes or front-end loaders). The table shows results for M/M/N queues, assuming that the service time and the ratio of arrival rate to number of servers are identical. As more servers are coordinated, the queues diminish.

Queue Parameter	A	B	C	D	E	F	G	H	I
# of Servers	2	4	6	8	16	24	32	40	48
Arrival Rate (# / hour)	100	200	300	400	800	1200	1600	2000	2400
Service Time (min)	1	1	1	1	1	1	1	1	1
Expected Time in the queue	2.27	0.99	0.59	0.40	0.15	0.07	0.04	0.03	0.02
Expected Time in System	3.27	1.99	1.59	1.40	1.15	1.07	1.04	1.03	1.02
Expected # in the queue	3.8	3.3	2.9	2.7	1.9	1.5	1.2	1.0	0.8
Expected # in System	5.5	6.6	7.9	9.3	15.3	21.5	27.8	34.3	40.8

Table 5.5 Terminal Cooperation Quantitative Analysis

For example, if one A terminal with two cranes cooperates with a C terminal with six cranes, the new system works as an integrated M/M/8 system. The average time in the queue at the A terminal is decreased from 2.3 minutes to 0.4 minutes, which is 83% reduction, and the average waiting time in the queue at the C terminal is decreased from 0.6 minutes to 0.4 minutes, which is a 33% reduction. And the total number of containers in the queue is decreased from 6.7 to 2.7, a 60% reduction. From this example, we can see that smaller terminals can get bigger benefit than big terminals from cooperation. If the terminals have the same size, they will get equal benefit from coordination. Four B terminals with 4 cranes each cooperating together could decrease the waiting time in the queue 90%, and reduce the number of containers in the queue from 13 to 2 for the whole system including all four terminals.

However, if a large terminal already takes advantage of economy of scale, it may not wish to cooperate with other terminals if it is not reaching its capacity. For example, if an E terminal with 16 cranes (which means 800,000 annual lift capacity) is not reaching its capacity, it may not want to cooperate with the B terminals with 4 cranes, since the large terminal could decrease its average queue time and queue length by a very tiny amount. Fortunately, this is not the normal case. According to the intermodal terminal database [ITD01], 90 TOFC/COFC terminals have an annual lift capacity of at least 100,000 (about 2 cranes), only 28 of them have an annual lift capacity of at least 250,000 (about 5 cranes), and the four largest TOFC/COFC terminals have annual lift capacity of 700,000~900,000 (about 16 cranes). From this information, we know that most of the terminals are "small enough" to have incentive to cooperate with each other, and the benefit of time savings at queue is at least 50%--one worst case is that two terminals with 400,000 lift capacity work together and their queue time is reduced from 0.4 minutes to 0.15 minutes, then the time savings for crane operators of each terminal is about 1670 hours per year. Based on the average labor cost of $30 per hour, the savings per terminal is about $50,000 per year due to the regional terminal cooperation based on ITMIS.

5.4 Summary

Considering the costs of computer hardware, network, terminal management software, labor training, as well as several communication technologies used in the ITMIS, the initial cost of the system is about $560,000 for a ten-year period, and the yearly maintenance cost is $70,000. We did not include the cost of rail shuttles between rail-marine terminals. With 10% APR, the equivalent annual cost in a 10-year period for the ITMIS would be $160,000 per year, and the present value of total investment would be about $1 million. The same amount of investment on infrastructure could increase the sample terminal capacity by 1.5%.

The benefits of ITMIS could include many different areas. From cooperations among terminals and carriers (which is made possible by information sharing), and the real time inventory control in terminal, as well as reservation system, ITMIS could increase gate productivity and throughput, reduce peak hour demand rate, have savings on labor cost, make higher utilization of lift equipment and storage place, etc. Based on the assumption of 400,000 containers annual throughput, the benefit analysis summary is shown in table 5.6. Two major groups of benefits are considered: benefits for single terminal operation are stated on the upper part of the table, and benefits for regional terminal cooperation improved by information sharing are stated on the lower part of the table. The second column indicates different operating processes analyzed in this chapter, the third column lists summary of qualitative results could be obtained by using ITMIS, and the fourth column lists quantitative results for examples in the previous analysis by queuing models based on numbers from other studies or research.

	Process	Qualitative Result	Quantitative Example
Terminal Operation	Gate Service	Reduce waiting time	-25% in non-peak; -40% in peak period
			Save trucker cost $75,000 /year
		Decrease peak arrival rate	Decrease 20%
		Increase gate throughput	
	Loading/ Unloading	Reduce queue time	77% time saving in system
		Reduce queue length	Decrease queue length 90%
		Increase lift capacity	Increase capacity 15%~18%
			Save crane investment $0.5~$6.5 million
		Increase average lifts /hour	Increase 10%
			$300,000 ~$1.25 million annual savings
	Resource Allocation	More efficient utilization from optimization	Increase 10%
	Storage	Reduce turn-around time	
		Expand storage capacity by "just-in-time"	Increase 10%
Regional Terminal Cooperation	Gate	Reduce queue length	
	Loading/ Unloading	Reduce queue time	Decrease 15%
			$50,000 labor saving
	Resource Allocation	More optimal solution	Increase Performance 10%
	Storage	More optimal solution	Increase 5%
	Regional Benefit	Resolve congestion	
		Reduce pollution	

Table 5.6 ITMIS Benefits Summary

The quantitative examples show that ITMIS could help to increase terminal lift capacity by 15%, so that it may save new investment on crane from $0.5 million to $6.5 million depending on the type of equipment. ITMIS could also help to improve crane performance, which could save about $300,000 ~$1.25 million per year. ITMIS could also improve resource allocation and increase storage capacity by 5~10%. In sum, ITMIS could increase the total throughput of intermodal terminals by 5~10%, and the benefits of the ITMIS is equivalent to the infrastructure investment for an extra 20,000~40,000 TEU of new capacity for the sample terminal. Drewry Shipping Consultants Ltd estimates an investment cost yardstick of $18.5 million for each 100,000 TEU of new capacity. [WCTG98] Hence, the benefits of ITMIS could be a net present value of about $3.7 ~ $7.4 million.

In addition to the above benefit, there are many other kinds of potential benefits. For draymen, the waiting time at the gate processing could be reduced, saving about $75,000 per year, and the pickup and dropoff time and cost could be reduced. The customer service could also be improved, because more precise information of location and movement could be provided for the cargo, and a tighter schedule could be followed. For the public, less regional congestion could be result from less delay and shorter length of queues in the entrance of terminals, thus reducing the fuel consumption, noise and the air pollution.

ITMIS will enable better sharing of information, which will provide better support for planning and coordination, reservation systems, and regional terminal cooperation. However, the actual benefits from ITMIS would depend on success in achieving cooperation among regional terminals and among carriers and terminals, as well as in implementing reservation system and automatic optimization models.

Significant benefit could also be obtained from information sharing among regional terminals and carriers. Often, there is a group of terminals within a major metropolitan area. Some of these may have underutilized capacity and insufficient demand because of their location. It may be possible to use express shuttle service among these terminals and thereby utilize their idle resources. When a terminal is reaching its capacity during a period with peak demands, it could redirect some cargo to the terminal that has extra facility and equipment available. Thus the total throughput of total regional system would be increased to a higher level. By using ITMIS and shuttles between terminals, the regional terminals could be connected together as a virtual integrated terminal. By using resources of other regional terminals, expensive infrastructure cost of expanding terminals in urban areas could be saved.

In sum, ITMIS could provide many conceivable benefits with relatively lower cost. With real time information and optimization models, terminal managers could make better plans and schedules for resource allocation and improve terminal efficiency. With better communications among carriers and terminals, more accurate information could be provided for customers and terminal managers, and save time for delays of loading/unloading, pickup and dropoff. With information sharing among regional terminals, terminal coordination could be improved, and the service level of regional intermodal system could be increased.

Chapter 6 Conclusions and Recommendations

6.1 Conclusions

Information sharing is a major opportunity for improving the management of intermodal transportation. Intermodal transportation is a cooperative activity in which many different companies and organizations are involved, and those companies and organizations are using different information systems and different information technologies. By gathering all useful information together and letting everyone in the system share the information, each company can make optimal decisions based upon a systems view to save cost and improve service to their customers. Intermodal terminals are the right places to build bridges among these different intermodal network components; they are also the right places to collect information from different systems, to undertake optimization and other analyses, and to distribute the useful information to companies regarding transportation plans and requirements. Thus, the central management information system in intermodal terminals (ITMIS) is a key research area. It is possible to find methods to improve the coordination of components inside one terminal, to enhance coordination among terminals and carriers, and to achieve better coordination among regional terminals. Furthermore, this better coordination could help to improve performance not only of the terminals, but also of the whole intermodal transportation system.

Their location in urban area often prevents intermodal terminals from expanding their physical facilities at low cost and small environmental influence. However, urban location is an advantage for using information systems. High-speed optical networks are available in metropolitan areas, and satellite receiver centers as well as wireless communication centers also focus on urban areas. Hence, much less investment would be required to build a communication network and central information system in urban areas than in rural areas. This is the second reason that we recommend information technology as a strategy for increasing the capacity and improving the performance of intermodal terminals.

Based on the above thoughts, I proposed the architecture of an Intermodal Terminal Management Information System (ITMIS). ITMIS integrates central database system and several modules for data entry, information queries, reservations, terminal management and information sharing with other terminals or systems. Among these components, the central database system is a key because it is responsible for storing real time data, as well as storing the terminal resource inventories and operation schedules. Furthermore, all the modules are connected to the central database system either to input or extract information. The reservations module is new for rail intermodal terminals, although it has been used in many other transportation areas such as airline ticketing.

The objective of this paper is to design the architecture of Intermodal Terminal Management Information System from a systems view, and to identify information technologies that are capable of supporting the performance requirements of ITMIS. The major concern here is the structure of information system, not the special characteristics of the technology. Because information technology is developing very fast, new technologies that are more effective for terminal information systems may appear in the next few years, and they may be used in ITMIS to supersede old technologies with similar functions. However, the basic idea of information sharing and the proposed structure of ITMIS should remain useful, since the operation of intermodal terminals and potential information flows are not expected to change dramatically over the next ten years.

Based on their current capabilities and characteristics, several information technologies could be chosen to be used in ITMIS to allow accurate and precise real time information gathering and transmission:

- AEI technology could be used for cargo and vehicle tracking and positioning inside the terminal;
- Differential GPS could be used for carrier tracking outside the terminal;
- Digital CCTV system could be used for supervising the operations of lifting, loading/unloading, pickup/dropoff, and crew management;

- High-speed network hardware and software could ensure the large volume data transmission including video and images.
- Some terminal management software and optimization models could also be integrated in ITMIS to make full use of gathered information.

In this paper, cost and benefit analysis is done for a hypothetical large intermodal terminal with annual throughput of 400,000 containers. The result shows that investment in ITMIS of no more than $1 million would produce much greater benefits over a ten-year life period. According to both quantitative and qualitative analysis in chapter 5, the potential benefits of ITMIS are:

- Improved terminal resource utilization;
- Higher productivity and reduced operating cost;
- Availability of freight information for optimizing terminal operations and schedules;
- More effective use of information among multimode carriers and terminals;
- Provision of information to transportation companies for better supply chain management.

The quantitative examples show that ITMIS could help to increase terminal lift capacity by 15%, so that it may save new investment on cranes from $0.5 million to $6.5 million depending on the type of terminal. In addition, ITMIS could reduce queue length and delays at the gate, reduce waiting time for loading/unloading, save truckers or draymen time to pickup/dropoff containers, improve resource allocation, and increase storage capacity. As a bonus benefit, information gathered by ITMIS could be used for further research of intermodal terminals, such as forecasting demand, identifying capacity bottlenecks, and simulating terminal operations, etc.

In sum, the cost of ITMIS is about $1 million, which equals the infrastructure investment for an extra 1.5% of new capacity for the sample terminal. ITMIS could increase the capacity of intermodal terminals by 5~10%. The benefits of the ITMIS is equivalent to a net present value of \$3.7 ~ \$7.4 million, which equals the infrastructure investment for an extra 20,000~40,000 TEU of new capacity for the sample terminal.

6.2 Recommendations

In this paper, I focus on information system and technologies as a method to help the components of intermodal networks to coordinate better. The main functions of ITMIS are to a) provide more accurate and real-time information and b) allow better communications and information sharing among different companies. How much actual benefit could be achieved would depend on the current level of coordination among carriers and terminals. There is already some coordination among different terminals owned by the same company, and there is already some information sharing among carriers and terminals. However, the current coordination is far from what is possible because of competitive, historical, or technological problems. Coordination can be improved, and improved coordination will lead to better performance of intermodal transportation.

The idea of seamless supply chain management throughout the world requires better intermodal freight transportation, and some carriers and intermodal terminals have realized the importance of coordination. Many efforts are being made to build better partnership for intermodal transportation. For example, some research is being done for building partnerships based on policy, guidelines, legislation and other legal issues, institutional issues, community involvements, etc. [GDMS99] [PPEF00] Thus more and more carriers and terminals will have incentives to improve their coordination.

Depending on the coordination extent among transportation companies, ITMIS could be useful at three different levels, and terminals could choose any level of ITMIS that is more suitable for their special situations.

The basic level is the management improvement of an intermodal terminal. Most prior research has concentrated on specific processes or information technologies, without paying enough attention to the overall management issues and information flows for the whole terminal. Real-time resource inventory control in ITMIS could help to increase resource utilization or save equipment-renting cost. Reservation systems in ITMIS could help terminal managers to make better operation plans and schedules, and provide better customer service. Real time detailed operation information (e.g. video and images) within terminals could help managers in a control center to monitor every terminal process as effectively as they could on the site.

The second level is coordination among one intermodal terminal and all carriers that go through this terminal. This kind of coordination is being implemented by some companies, but most information is not real-time, and information sharing could be further improved by ITMIS. Information of more accurate arrival and departure times from other carriers could make "just-in-time" pickup and dropoff more feasible. Reservation system could provide opportunities for carriers to illustrate their special requirements and help terminal managers adjust peak demands by using a pricing strategy. Terminal service information such as estimated turnaround time and delays could help customers to choose better connections for their cargo, and terminals could experience less unexpected congestions.

The third level is coordination among terminals within a region, including similar terminals owned by the same company, similar terminals owned by different companies, and terminals of different transportation modes, such as rail-highway and marine-highway terminals. This kind of coordination has been implemented in a few areas, but there is so there is still a great opportunity to improve performance by using information from ITMIS and sharing the information among terminals. Information sharing could help these regional terminals to work together like a single virtual terminal. Terminal managers could share equipment, storage spaces, and other resources. They could also adjust peak demand and insufficient demand among different terminals, obtaining better performance through system optimization.

6.3 Further Research Topics

This thesis focuses on two themes: a) the communication and information sharing among regional terminals and transportation companies, and b) the information system architecture. Further research could be done on information sharing over larger areas or partnerships among all the components of the whole intermodal network. For example, if a container is scheduled to be shipped from New York to Texas, the shipment might normally be sent via Chicago. But when the information is shared in the whole intermodal network, the shipping company may find that there is congestion in Chicago area, while St. Louis has some terminals available to handle the connection, so that the new trip through St. Louis could save time and cost. Thus a more optimal solution is reached for the carrier; the Chicago terminal would not experience more congestion due to extra load; while the St. Louis terminal would earn money for their underutilized resources. This is a win-win strategy on a national scale similar to what has been described in this thesis for terminal integration in regional areas. After some ITMIS experiments are made in regional terminals, broader uses of ITMIS could be investigated. Simulation models could be built to predict the influence of ITMIS for region or for the whole intermodal network.

Another possibility for improvement could be on connections between ITMIS and other information systems related to intermodal transportation. The highway, rail, ocean, and air transportation systems are using many different information systems for all kinds of management and control; the passenger traffic and freight transportation systems are also using different information systems. When duplicate information is collected for such different systems, IT investment is at some level wasted. As we suggested in ITMIS, we will not only share the information in intermodal terminal system to other companies, but also use the information from other systems as data entry. Thus the ability to create connections and share data among different information systems needs to be investigated in more detail.

This thesis has provided some quantitative analysis for terminal operations and regional terminal cooperation using queuing theory. Better estimates of benefits can be by making experiments on some terminals with ITMIS, then building a simulation models to forecast the effects of ITMIS on the performance of terminals. Data collected from the real world would be more realistic and helpful for evaluating and promoting ITMIS. Experiments could be based on different levels of ITMIS, could implement, monitor and evaluate parts of the system, and could evaluate some or all of the technologies discussed in this paper.

6.4 Summary

Finally, I would like to re-emphasize the basic idea in this paper: accurate information and information sharing in the intermodal transportation network are very important, as they could save a lot of investment and provide benefits in many areas. Information systems and technologies are relatively cheap and free of environmental impact. ITMIS could help intermodal terminals to optimize their operations and save cost, and help regional terminals to cooperate with each other based on shared, coordinated information. ITMIS may induce benefits for resolving congestion in urban areas by balancing the traffic between rail and highway, and it could also be helpful for the whole intermodal network transportation.

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