

OPTIMIZATION OF CHASSIS REALLOCATION IN DOUBLESTACK
CONTAINER TRANSPORTATION SYSTEMS

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CONTAINER TRANSPORTATION SYSTEMS

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By

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CHAPTER 1
INTRODUCTION

1.0 Brief Overview

This dissertation addresses the issue of chassis logistics associated with containerized freight movements in the intermodal transportation industry. The focus of the associated research effort is the development of a model that provides solutions to chassis logistic problems that typically occur in industry. Subsequent to model development is the incorporation of the model into a software system that provides decision support for chassis fleet management on a continuing basis. Requirements for such a system include the ability to provide solutions in a reasonable time frame while featuring a favorable operating environment for the user. Chassis logistics problems are similar in structure to other problems in the transportation industry. Thus the knowledge gained in this effort may prove useful in other transportation applications.

1.1 Objectives of the Research

There are four objectives of this research:

1. Construct a model that provides minimum cost solutions to chassis allocation problems and characterize the complexity of the model in order to demonstrate its practical significance.
2. Develop a software system that incorporates the model as a basis for decision support in chassis fleet management issues.
3. Evaluate the effectiveness of the solution software in scenarios supported by data collected from industry.
4. Propose and assess strategies for integrating the software into operational environments.

Achievement of these objectives requires knowledge and skill from two distinct fields:

1. Development and analysis of models to solve large decision problems requires skill in the field of operations research.
2. The incorporation of these models into functionally practical software systems requires development skills associated with the field of computer science.

1.2 Significance of the Research

The significance of this work is rooted in the issue of equipment utilization in the intermodal transportation industry. Effective equipment management translates into lower capital equipment investment and fewer equipment shortages that can be costly and disruptive in daily business operations. Ineffective management of equipment assets is generally agreed upon as universal problem in the intermodal industry. This is evidenced by the fact that turn-around times for intermodal containers average 1.7 times per month versus 4 times per month for over-the-road trailers [Sparkman, 1994]. Recent industry resolutions to equipment utilization problems involved additional investment in equipment to offset shortages (see for example Richardson [1994], or MacDonald [1994]). At present, intermodal equipment shortage problems have been relieved due to the recent equipment investments. However an acknowledged lack of control of asset utilization, most particularly with respect to chassis, is among the most important challenges facing the intermodal industry (see Anonymous, Traffic World [1994] or Sparkman [1995]). Improved use of information available through computerized information systems is an alternative that can assist in addressing these problems.

Certainly intermodal equipment utilization problems involve more than reduction of equipment and operating cost in chassis fleet

management. However it is likely that success in resolving chassis logistics problems could result in better understanding of supply and demand structures in addition to improved planning and forecasting in the industry.

1.3 Dissertation Organization

The remainder of this dissertation begins with a description of the current system in Chapter 2 that is initiated by a review of the historical development of container based intermodal freight transportation. Chapter 3 is a review of the related literature that illustrates the absence of information that effectively addresses chassis reallocation issues. A detailed solution model for chassis reallocation is presented in chapter 4 and is followed by the discussion of a software implementation of the model in chapter 5. An exploration of computational issues and related software experience is in chapter 6. This is followed by a study of research applications in chapter 7. Conclusions and directions for further research are addressed in chapter 8.

CHAPTER 2

SYSTEM OVERVIEW

2.0 Definitions and Descriptions

The term "intermodal" as applied in the transportation industry refers to the involvement of more than one form of carrier during the movement of freight from source (the shipper) to destination (the consignee). The form of a carrier refers to the mode of transportation employed by the carrier, with typical examples being railcar, highway truck, aircraft, or ocean vessel transport. Most intermodal cargo must be reloaded in the transition from one mode to another. The dominant forms of intermodal transportation in practice today involve mixes of rail-truck, ocean-rail, and ocean-truck transport. The two most common forms of intermodal rail transport services are TOFC (trailer on flatcar) and COFC (container on flatcar). TOFC involves the transport of an entire highway trailer containing freight on a railcar. COFC services require the loading of containers of freight from either a ship or a truck for the rail portion of the journey.

A typical example involves a truck hauling a load from a shipper to an intermodal terminal. At the terminal the load is secured on a flatcar (COFC or TOFC) and hauled some distance by rail to another intermodal terminal in the vicinity of the consignee. The final segment of the journey is the haul from the second terminal to the consignee. In industry terminology a haul by truck to or from the terminal is a "short haul" and the longer trip by rail is the "line haul". Note that the rail portion of COFC services involves transport of containers only. This allows containers to be stacked in specially designed doublestack cars for

vertical space efficiency. Containers that are to be hauled by truck must be attached to highway chassis designed to mate with containers. Individual chassis configuration requirements are tied to container size which is commonly 20 and 40 feet in length for international containers and 45, 48, and 53 feet for domestic containers. Extendable chassis exist that are capable of accommodating domestic containers sizes of 48 or 53 feet. COFC movements and the inherent logistics problem of satisfactorily mating containers and chassis is the primary focus of this paper.

2.1 COFC Service Review

2.1.1 COFC History

The origins of modern container based intermodal transportation go as far back as the late eighteenth century in England. In this instance coal was hauled in iron crates by horse drawn trams to a nearby canal and loaded by crane onto ships [McKenzie et al., 1989]. Experiments continued on a relatively small scale throughout the nineteenth century in both England and North America, with American examples involving both ship and rail transport. Sustained ventures into containerization did not occur until after World War I when transfer delays, high operating costs, and disproportionate damage claim ratios associated with less-than-carload (LCL) shipments troubled U.S. rail companies who were required to offer the service [Mahoney, 1985]. Benjamin Fitch developed a system for LCL intermodal transfer using trucks with demountable bodies that was first demonstrated in Cincinnati in 1917. He formed the Motor Terminals Company to service LCL rail traffic in the Cincinnati area after the war. This service, however, was short-lived due to the poor financial condition of the local interurban railroads [McKenzie et al., 1989]. Fitch later

developed an intermodal system employing flatbed trailers, flatcars, sliding transfer equipment, and special insulated tanks for carrying milk from dairy sources to markets in urban areas. He formed the National Fitch Corporation and implemented his system successfully beginning in 1940 until the early 1950s [McKenzie et al., 1989].

New York Central Railroad also experimented with containerization in the 1920s in response to LCL shipment problems. The New York Central initially used 2800 pound steel containers placed in gondola cars to carry department store merchandise from New York to Chicago and later contracted with the U.S. postal service to transport mail in the containers [McKenzie et al., 1989].

The Pennsylvania Railroad, a chief competitor with the New York Central, operated a container service in the late 1920s that transported containers on flatcars fitted with mounting brackets. However this was more of a boxcar service since the containers were usually loaded and unloaded while still on the flatcars [McKenzie et al., 1989].

Although the aforementioned services employed containers largely in a combination of rail-truck services, they were never a significant business and were practically non-existent by the early 1950s [McKenzie et al., 1989]. A major reason for the lack of successful COFC or TOFC services during this period were restrictive regulatory policies enforced by the Interstate Commerce Commission (ICC) from 1931 through 1980. The ICC ruled in 1931 that commodities shipped in containers by rail must move at traditional high rail class (commodity-based) rates, rather than at lower flatcar rates [Mahoney, 1985]. This ruling effectively prevented railroads from competing with truckers in the merchandise freight market, allowing the truckers to dominate the market through the 1970s. Other

reasons cited for the lack of intermodal freight industry development during the mid-twentieth century include government restrictions on establishing multi-modal companies to coordinate services, lack of commitment on behalf of railroad management, and railroad resolve against rail-truck cooperation [McKenzie et al., 1989; Mahoney, 1985].

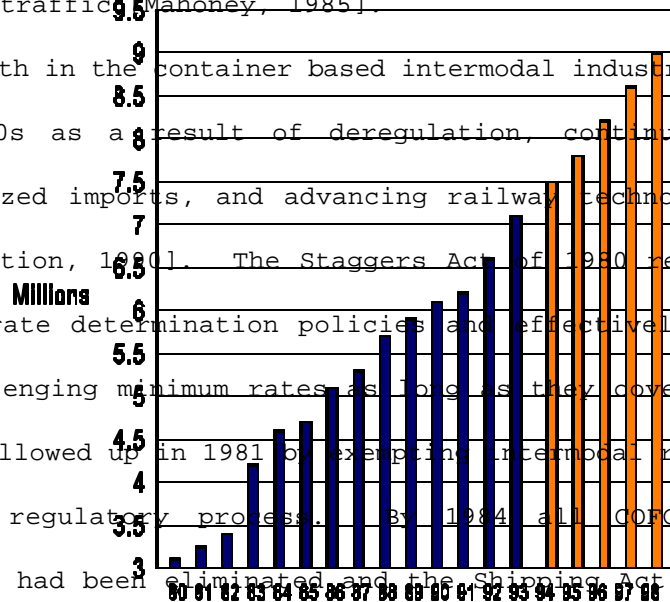
The situation began to change in the 1950s when the ICC ruled in 1953 that hauling trailers by rail on flatcar was considered a rail transport and thus did not require a motor carrier certificate. Shortly afterward steamships carrying cargos of container freight began operating in the maritime shipping industry. These "containerships" originated with Malcom McLean and the Pan Atlantic Steamship Company in 1956 [Mahoney, 1985]. The "container revolution" caught on very quickly and replaced traditional breakbulk shipping as the dominant form of ocean goods transport over the next two decades. In the 1960s marine containers began to appear on railroads. They became common in the 1970s as so called "landbridge" intermodal services developed for the shipping of goods from overseas to inland or overseas destinations.

Landbridge refers to transfers of containers from ship to rail at a port on one coast followed by a rail haul to the other coast where the containers are loaded on another ship for transport overseas. Landbridge services came about with the growth of Pacific Rim export countries and their transport of goods to destinations in Europe and America. These routes are known to save significant time over all-water routes through the Panama Canal [McKenzie et al, 1989]. Services related to landbridge include minibridge and microbridge transport. Minibridge refers to enterprises that serve a second port by land transport from a single port call. In other words, the containers are destined for a second inland

port instead of an overseas port as in landbridge services. Microbridge refers to services that connect inland origin destinations with ocean container traffic [Mahoney, 1985].

Figure 2.1 Intermodal Loadings / Projections: 1980-1998

Growth in the container based intermodal industry accelerated in the early 1980s as a result of deregulation, continued rapid growth of containerized imports, and advancing railway technology [U.S. Dept. of Transportation, 1990]. The Staggers Act of 1980 relaxed regulation of railroad rate determination policies and effectively prevented the ICC from challenging minimum rates as long as they covered variable costs. The ICC followed up in 1981 by exempting intermodal rates on rail service from the regulatory process. By 1984 all COFC/TOFC traffic rate regulation had been eliminated and the Shipping Act of 1984 facilitated



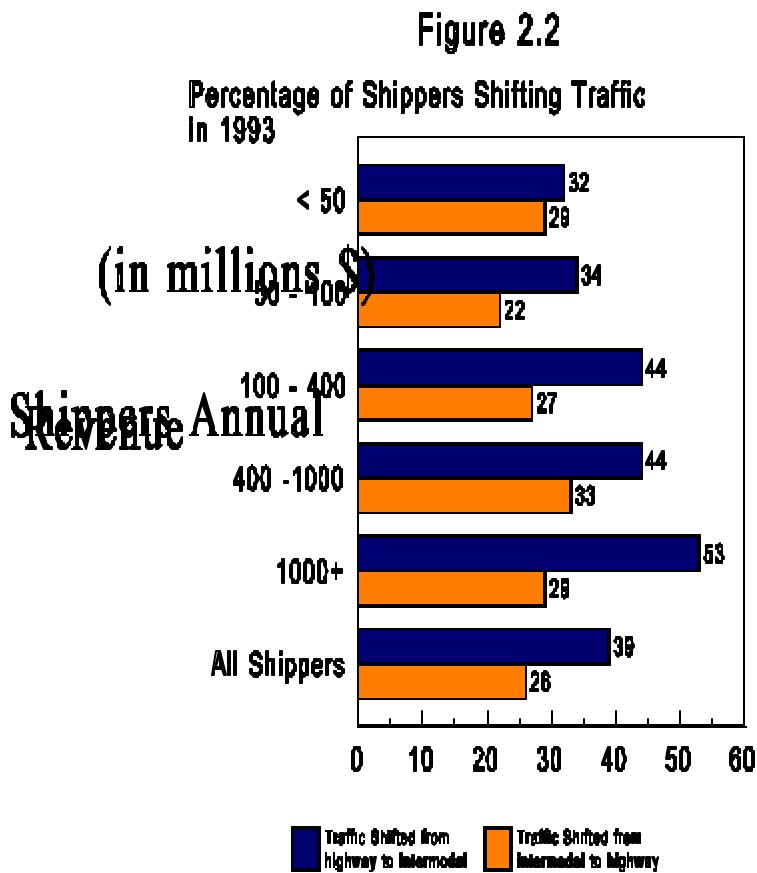
intermodal billing consolidation. Doublestack railcar technology introduced in the late 1970s and early 1980s provided a means for improved cost efficiency and service quality. Doublestack cars are lighter than conventional flatcars and permit containers to be stacked, resulting in a more efficient use of vertical space, improved aerodynamics, and considerable fuel savings. Since these cars are articulated, ride quality is improved and freight damage is reduced [U.S. Dept. of Transportation, 1990].

Source: Spasovic [1990], Raper [1994]

2.1.2 Current COFC Conditions

There is little question that intermodal freight transportation is a strong growth industry. Figure 2.1 shows the actual and projected pattern of growth of intermodal loadings from 1980 through 1998. Recent reports have placed intermodal growth at higher than projected levels of 13.5% in 1994 over the same period in 1993 [Sparkman, 1994]. Another indication of

the strength of the industry is shown in Figure 2.2.



Traffic switching from highway to intermodal exceeded traffic switching from intermodal to highway across the board in 1993 and is most

Source: Spizziri [1994]

significant in companies with revenues exceeding one billion dollars [Spizziri, 1994]. Unfortunately, data depicting the breakdown between TOFC and COFC intermodal traffic is scarce, but recent data published by the Association of American Railroads indicates that COFC traffic loading comprises the majority of intermodal traffic and that the COFC share is growing with respect to TOFC (See Table 2.1 below).

Table 2.1 Cumulative Traffic Originated, 1st 51 Weeks of Years Shown *

Traffic	1994	1993	% Change
Trailers	3,821,244	3,458,406	10.5
Containers	4,345,922	3,692,051	17.7
Total	8,167,166	7,150,457	14.2

* Source: Association of American Railroads 1/25/95

Present concerns in the intermodal industry center on asset utilization with respect to intermodal equipment. Although recent equipment investments have resolved earlier equipment shortage problems, there is also concern that existing equipment is not being utilized efficiently and that improved management of assets is needed. Suggested means of improvement include better use of information systems, rail scheduling, and interchange management.

2.1.3 Chassis Management

The nature of COFC service in rail-truck environments requires maintenance of a separate chassis fleet for highway transport. Containers

arriving at intermodal terminals must be loaded on an available highway chassis in order to be moved by truck. Conversely, containers must be detached from truck and chassis to be loaded on departing trains. This situation raises logistical questions concerning where, when, and how chassis should be positioned in order to insure the proper matching of chassis to containers.

Chassis management issues originated with the growth of marine-rail container transport in the 1960s. During that period neutral chassis pools were developed by leasing companies to relieve carriers of the burden of chassis management. The leasing services owned and maintained pools of chassis that would mate with standard size containers, charging daily rates for chassis rental. However, the proliferation of leasing companies led to space problems at terminals that forced chassis lessors to move to off-terminal locations. As a result leasing costs continued to rise and many carriers chose to invest in the acquisition and management of their own chassis fleets [Braun, 1987]. In the late 1980s the neutral pool concept surged again with the advent of doublestack intermodal services [McKenzie et al., 1989]. This time fewer leasing companies set up operations at larger terminals, often contracting with a single rail or marine carrier at specific terminals.

In the 1990s the deregulated market has tempted new carriers into the intermodal market [Raper, 1994]. The concept of neutral chassis pools operated on a national level continues to be discussed as a solution to chassis management problems [Sparkman, 1995]. However, new carriers and established carriers alike continue to choose to own and manage their own COFC highway chassis fleet. In some cases carriers have opted for non-standard chassis-container combinations that limit the possibility of their

inclusion in neutral pools [Anonymous, Traffic World 1992].

Historically, chassis management practices have consisted of investing in large and under-utilized chassis fleets. Automated equipment tracking systems and advancing computer technology may provide means for improvement.

CHAPTER 3

LITERATURE REVIEW

3.0 Introduction

A review of literature focusing on transportation, computer, and operations research journals reveals no published work presenting solution procedures for chassis fleet management under central control in intermodal operations. The chassis fleet problem investigated in this work is similar in structure to a number of other problems addressed in the literature. Proposed solutions to these problems may be classified as operational level models in that they impact short term decisions made in daily business operations. Other models that address medium or long term decisions are classified as tactical or strategic models.

Examples of operational problems in the transportation industry include vehicle routing and scheduling problems as well as driver/crew assignment and scheduling problems [Powell, 1991]. More closely related to the subject of this work are fleet management problems and the various models in the literature that address them. Fleet management models generally involve the positioning of a fleet of vehicles or other similar equipment over a given period of time in response to given or forecasted demands. The types of fleets considered by transportation models include trucks, railcars, aircraft, and containers. Of particular interest to this work are those fleet management models that focus on empty vehicle or container positioning problems. Also of interest are a small set of models in the literature that address problems specific to intermodal operations.

The remainder of this review consists of a discussion of empty

equipment allocation models in the next section followed by a review of the intermodal models of interest to this work.

3.1 Empty Equipment Models

White and Bomberault [1969] developed a model for empty freight car allocation in railroad systems. The authors formulate the problem as a space-time network flow problem that can be solved using linear programming techniques applicable to minimum cost flow network problems. The model incorporates four rules of flow for cars in the network as follows:

1. Cars become available at nodes in the network representing specific points in time. They are either available at the beginning or become available at locations as time progresses.
2. Cars are either required at nodes in the network during the period of solution or they remain available at the end of the time span.
3. For any node at any given time the number of cars arriving plus the number of cars that become available is equal to the number of cars leaving plus the number of cars required there.
4. The flow of cars is positive in time, cars cannot go backward in time.

The formulation for the problem has a minimum cost objective with constraints that represent the rules of flow described above. An solution algorithm is described that uses an inductive method of solving successive subnetworks of the problem until the overall network solution is reached.

White [1972] subsequently applied the solution principles of the empty freight car problem to the distribution of empty containers.

Misra [1972] also formulated a model of solution for the empty freight car allocation problem. This model represents the problem as a linear program with an objective of minimizing the total empty hours of

the freight car fleet. Total empty hours are defined as the sum of waiting times at origin and destination stations plus the travel times between the stations. The constraints of the model represent route capacities and congestion definitions as well as supply and demand specifications.

Mendiratta and Turnquist [1982] developed a model for empty freight car distribution consisting of two interacting submodels. A network submodel maximizes profits over the entire network as constrained by empty freight car supply and demand. A terminal submodel incorporates inventory control principles for stochastic demands and lead times in empty freight car delivery. The models interact by iteratively exchanging shadow prices for cars in the network until the results of the submodels are consistent.

At any given iteration the shadow prices for empty cars in the network represent the marginal value of the cars at their current location. The network model is a linear program that maximizes revenues less cost associated with moving empty cars between terminals subject to gross supply and demand at each terminal. Each solution of the network model generates a new set of shadow prices for cars in the network which are used by the terminal submodels representing each terminal in the network.

The terminal submodels combine the generated shadow prices with shortage costs and order/release costs to determine the desired inventory of empty cars for particular terminals. This information is then transmitted back to the network submodel to solve for the next set of shadow prices. The network submodel solution effectively reduces the prices of resources in excess supply and increases the prices of resources for which there is excess demand. The exchange of information between the submodels continues until the results for the submodels match and the solution is

considered optimal.

Kikuchi [1985] developed a model for dispatching empty railcars from freight car pools to demand points at minimum cost. The model is represented as a linear program with an objective of minimizing the sum of car shipment costs, car storage costs, holding costs for cars held at the end of the period, and penalty costs for car shortages. The constraint equations of the model are defined as follows:

1. Cars becoming available at unloading points throughout a day must be dispatched to loading points or held for the remainder of the planning horizon.
2. Daily demand for cars at loading points must be satisfied by cars in the system and by cars dispatched in response to shortages.

The solution procedure presented involves the formulation of the model as a transshipment problem that is solved as a linear programming problem.

Crainic et. al [1993] proposed models for the allocation of empty containers in land distribution and transportation systems in the context of international maritime shipping. The basic model discussed is a deterministic single commodity model, where single commodity means that container size substitutions are not allowed. The transportation system as defined consists of port depots, nonport depots, supply customers, and demand customers. Port depots are sources of containers at harbors where containers enter and exit the system. Nonport depots are inland depots where containers may be held before being transported to meet demand at other depots and customer locations. Supply customers refer to customers that have containers available after unloading them. Demand customers require empty containers for the loading function.

The objective of the model is to minimize the sum of costs during a

given time period from the following sources:

1. The transportation of empty containers from depots to demand customers.
2. The transportation of empty containers from supply customers to depots.
3. The transportation of empty containers between depots.
4. The holding costs of empty containers at depots.
5. Costs of bringing in containers from outside the system.
6. Penalty costs for not satisfying demand for empty containers at ports.

The constraints of the model are defined as follows:

1. The volume of empty containers allocated in a period for each customer is equal to the customer demand minus the volume of containers whose shipment to the customer was initiated prior to the start of the period.
2. The volume of empty containers picked up during a period at each customer is equal to the supply of empty containers that become available at each customer location.
3. The stock of empty containers available at each nonport depot at the end of a time period is equal to the stock at the beginning of the period plus the flow of empty containers arriving during the period minus the empty containers departing during the period. Arriving empty containers are defined to be those en route at the beginning of the period plus those arriving from external sources and other depots and supply customers. Departing containers are those sent to other depots and demand customers during the period.
4. The stock of empty containers available at each port depot at the end of a time period is defined similarly to that of nonport depots except that export demand at each port depot must be subtracted and import supply must be added. Export demand represents external empty container demands that are shipped on departing containerships. Import supply is empty containers that come from external sources on arriving containerships.
5. Balancing movements (i.e. flows between depots) are carried out according to exogeneous bounds defined by policies and agreements with carriers.

The suggested method of solution for the model described above involves its transformation into a dynamic network model applied in a rolling horizon framework. However specific algorithms for model solution are not presented.

Gao [1994] presented an approach for operational control in maritime shipping that includes the positioning of empty containers to correct imbalances during a planning period. A two stage process is defined with the initial stage concerned with identifying imbalances between supply and demand for empty containers given that cargo flows, containership schedules, and average unloading times are known. The second stage of the modelling process involves correcting the imbalances in the first stage with a minimum cost linear programming formulation whose objective function cost terms are defined as follows:

1. Storage costs of empty containers between voyages at each port.
2. Costs of positioning empty containers between ports during voyages.
3. Costs of leasing/letting containers during consecutive voyages at each port.
4. Capital costs of owning containers during consecutive voyages at each port.

The constraints of the linear program are given as:

1. The number of empty containers available at a port after a voyage equals the number available after the previous voyage plus the net of leased/let containers and the net of positioned containers minus the given imbalance.
2. The number of positioned empty containers arriving at a port i from another port h on a voyage equals the number of positioned empty containers leaving port h for port i on the voyage.
3. Arriving empty containers take up space that is not greater than space reserved at the receiving ports.
4. Departing empty containers take up space that is not greater

than space reserved at the destination ports.

5. The net of leased/let containers are not greater than the number of containers available for leasing/letting.

Solutions to the hypothetical cases discussed were reached with the use of commercial linear programming software packages.

3.2 Intermodal Models

The work of Sinclair and Dyk [1987] addresses movements of containers by truck as a result of import and export activity at a maritime intermodal terminal. The described model considers the movement of containers between clients and between clients and the container depot at the intermodal terminal. All movements resulting from client supply and demand are considered, including truck movements with empty containers, full containers, and no containers. Chassis/container mating issues are not considered except in the context of containerless truck movements with or without chassis - both are unproductive. The objective of the model is the minimization of time spent on unproductive movements and waiting time between movements. The constraints discussed include client time window restrictions, driver shift restrictions, linking of related movements, client storage capacity, and company priorities for movements.

A heuristic for model solution is presented since a mixed-integer linear programming formulation of the problem is too large for practical implementation.

The heuristic consists of two phases relating to preprocessing and scheduling. The preprocessing phase involves examining expected movements and determining feasible starting and ending time windows for the movements. Lists of movements and lists of clients with common

characteristics, as well as a priority list of movements, are also constructed during the preprocessing phase. The scheduling phase implements a repeated selection of unscheduled movements from the priority list and adds movements before or after the priority movement according to the minimum sum of unproductive movements and waiting time added to the trip. When a complete route is formed, a vehicle is assigned to the route and the priority list is updated for selecting the next unscheduled movement.

In practice, the schedules developed using the heuristic often require adjustment as a result of scheduling conflicts.

Chih, Bidden, Hornung, and Kornhauser [1990] present a model for management of intermodal doublestack trains and discuss the implementation of the model in software. The model addresses marine-rail intermodal operations - specifically container loading and route selection aspects of COFC service. Highway chassis logistics are not included in this model.

The problem is presented as a cost minimization problem in a time-space network. Constraints on the system consist of fleet size constraints, car capacity constraints, container size constraints, and minimum car load constraints. The heuristic solution procedure is sequenced as follows:

1. Generate a time-space network based on train schedules and physical characteristics of the network.
2. Account for the flow of cars in route in the network.
3. Route containers through the network that have been preassigned to specific trains.
4. Route non-preassigned containers through the network based on least initial cost.
5. Reroute the containers in step 4 based on updated costs from estimated train length.

6. Use a network transshipment problem to match container flows with available cars.

Spasovic [1990] developed a model concerned with the minimization of costs associated with the short haul highway portion of rail-truck intermodal transport. The model targets TOFC services exclusively and so does not address COFC operations or chassis logistics. The constraints in the model are time window constraints and fleet capacity constraints. The model accounts for various drop off and pick up policies in order to determine solutions that satisfy demands within a given level of service.

Two heuristic procedures are presented for model solution. First a two-stage solution procedure is presented that solves two sub-problems formulated as linear programs in order to obtain integer solutions. The second procedure is a multi-stage process that obtains improved integer solutions by exploiting the structure of the model.

Nozick [1992] presented a model of integrated rail-truck intermodal operations that provides solutions for activities within a basic time period of one day. Activities consist of load movements between shipper and consignee, movements of empty cars between terminals, and movements of empty trailers and containers between terminals. The basic model applies to TOFC operations and possible incorporation of containers in the model is only discussed with respect to the load assignment and conservation of flow constraints. Chassis fleet considerations are not included in the model, effecting the assumption that COFC operations are equivalent to TOFC operations.

The model is formulated as a large integer program with a minimum cost objective. Cost components consist of costs associated with satisfying load demands, repositioning empty trailers, and repositioning

empty flatcars. Constraints are formulated for level of service (i.e. time window) requirements, trailer fleet conservation, and flat car conservation. The method of solution is a heuristic procedure based on the LP relaxed solution.

Barnhart and Ratliff [1993] present a methodology for determining minimum cost intermodal routing in a rail-truck context with no distinction made between TOFC and COFC routings, which means that chassis logistics are ignored. Routing problems with rail transport cost expressed per trailer are shown to be solvable using simple shortest path procedures. Routing problems with rail cost expressed per flatcar are shown to be solvable when allowing at most two units per flat car. The solution procedure in this case requires the establishment of link costs on a pairs network. Such a network is shown to be solvable by weighted matching algorithms.

In summary, the results of the literature review indicate that no work has been published on solution models supporting chassis distribution decisions in centrally controlled intermodal operations. Published intermodal models have not addressed the problem of interest, although papers addressing similar problems are a source of ideas in solution approaches.

CHAPTER 4
SOLUTION METHODOLOGY

4.0 Introduction

A feasible approach to chassis management logistic problems is to develop a planning model that may be implemented periodically to suggest an allocation of highway chassis (timing, number, location) that will assure a successful and efficient mating of chassis to containers. Such a model would require inputs defining the state of the system at the start of a period along with the flow of containers planned during the period. Results from the model would define a cost efficient flow of chassis corresponding to the given container flow.

4.1 Problem Statement

Assume at a point in time that a certain number of centrally controlled intermodal terminals (ramps) are doing COFC business. These terminals have the technology required to separate containers from highway chassis and load them onto rail cars. This technology permits containers to be unloaded from rail cars and placed on available chassis. Trucks pulling loaded containers on chassis arrive at ramps throughout the day. The containers are loaded on rail cars and the chassis may remain in storage at the ramp. At scheduled times the trains depart the origination ramps and make the journey to destination ramps, arriving at scheduled times. At destination ramps the containers are unloaded from the rail cars and placed on available chassis before being driven to consignees by truck.

Chassis may be pooled at the ramps from previous supplying

operations or they may be loaded on rail cars and shipped from one ramp to another. In cases where ramps are located within reasonably close physical proximities, chassis can be driven by truck from one ramp to another.

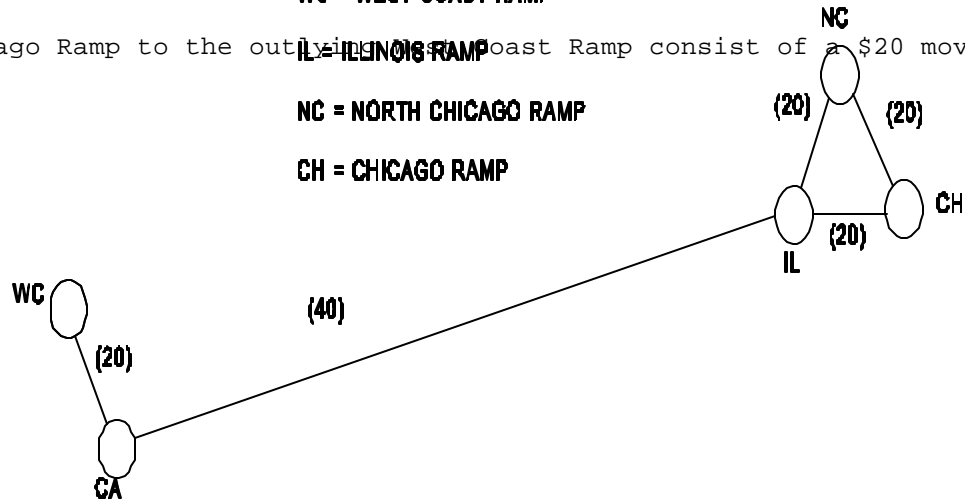
When containers arrive by rail at a destination ramp, it is necessary to mate them with available chassis. The nature of normal business activity does not guarantee that a sufficient pool of chassis will remain at all ramps since container loads vary depending on the day of the week and the season. Ramps that have more arrivals than departures over time could deplete a supply of chassis unless some action is taken to redistribute the chassis on a timely basis. A method is needed to determine when, where, how many, and by what means (truck, rail) chassis are to be moved from one location to another.

4.2 Solution Approach

4.2.1 A Uni-Directional Model

A solution approach to the chassis reallocation problem can be considered in terms of the classic transportation problem. Consider the transportation network shown in Figure 4.1 where the defined ramps exist in the Chicago and Los Angeles metropolitan areas. The numbers in parentheses in Figure 4.1 represent the unit cost of transporting a chassis between the connecting ramps. In this network, all chassis moved between the Chicago and Los Angeles areas are shipped by rail from the Illinois ramp or the California ramp at a cost of \$40. Chassis moved between ramps within the metropolitan areas are moved by truck at a cost of \$20. The transportation problem illustrated in Table 4-1a is one of shipping chassis from supply ramps in the Chicago area to demand ramps in

the Los Angeles area. Note that the costs displayed in the cells of Table 4-1a are additive between ramps. For example, a move from the outlying Chicago Ramp to the outlying West Coast Ramp consist of a \$20 move from



the Chicago Ramp to the Illinois Ramp, a \$40 move from the Illinois Ramp to the California Ramp, and a \$20 move from the California Ramp to the West Coast Ramp. The supplies are counts of chassis existing at the given ramps in the Chicago metropolitan area. The demands represent the number of chassis required at the given ramps in the Los Angeles area.

Figure 4.1 Example Chassis Transportation Network

TABLE 4-1a

	WC	CA	Supply
CH	80	60	2
IL	60	40	4
NC	80	60	6
Demand	5	7	

The application of transportation model solution techniques to the example of Table 4-1a gives the solution shown in Table 4-1b. The largest cost in the solution is shown in the third entry in Table 4-1b, interpreted as the

shipment of 5 chassis from the North Chicago Ramp to the West Coast Ramp at a cost of \$400.

TABLE 4-1b

<u>From</u>	<u>To</u>	<u>Amount</u>	<u>Cost/Unit</u>	<u>Total Cost</u>
CH	CA	2	60	120
IL	CA	4	40	160
NC	WC	5	80	400
NC	CA	1	60	60
			Overall Cost=	740

4.2.2 A Bi-Directional Model

The transportation problem of Table 4-1a assumes that chassis demands in the Los Angeles area are to be met with supplies in the Chicago area. A more realistic model would consider that there are train arrivals and departures at each ramp, resulting in both supplies and demands at each ramp. A train arriving with containers at a ramp requires chassis to mate with the containers upon arrival. This corresponds to a *demand* for chassis upon train arrival. A train departure means that containers are detached from corresponding chassis and loaded on the departing train. This means that there is a chassis *supply* upon train departure.

Since there are both arrivals and departures at all ramps, each must

be viewed as both supply and demand points. Note that a demand resulting from an arrival at a ramp can be met with a supply resulting from a previous departure at that same ramp. The example transportation problem represented in Table 4-2a uses the same transportation network shown in Figure 4.1. This example assumes that both arrivals and departures occur at each ramp. Note also in the following example that the cost of meeting a demand at a ramp with a supply at the same ramp is assumed to be zero. The supply values shown in Table 4-2a correspond to the number of containers loaded on departing trains since an equal number of chassis remain behind at the given ramps as a result of the departure. The demand values are counts of containers arriving by train at the given ramps that must be mated with chassis upon arrival. The solution to the transportation model of Table 4-2a is given in Table 4-2b showing a total

of 5 chassis movements required at an overall cost of \$140.

TABLE 4-2a		CH	IL	NC	WC	CA	Supply
CH		0	20	20	80	60	2
IL	20		0	20	60	40	4
NC	20	20		0	80	60	6
WC	80	60	80		0	20	5
CA	60	40	60	20		0	5
Demand	4	3	3	5	7		

TABLE 4-2b

<u>From</u>	<u>To</u>	<u>Amount</u>	<u>Cost/Unit</u>	<u>Total Cost</u>
IL	CA	1	40	40

NC	CH	2	40	40
NC	CA	1	60	60
			Overall Cost=	140

4.2.3 A Bi-Directional Time Based Model

The transportation model of the previous section requires additional refinement in order to complete its application to the chassis reallocation problem of interest. It is missing an important dimension in that it does not address the critical issue of *time*. Since supplies and demands in the chassis reallocation problem correspond to train departures and arrivals, they are dependent upon the departure and arrival times of the trains. In addition to *amounts* associated with supplies and demands it is important to specify the *time* associated with demand requirements or supply availabilities. Thus each supply and demand definition includes both an amount and a time.

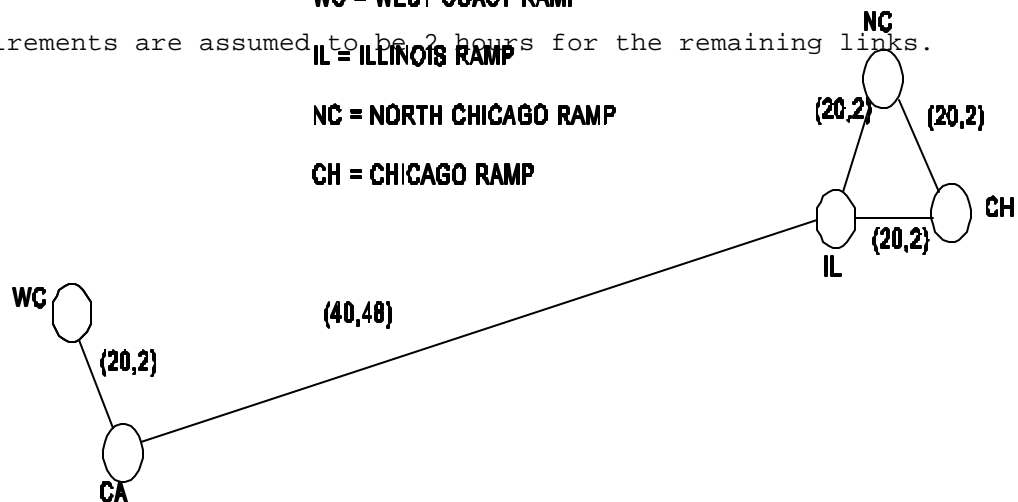
The time attribute of the supply/demand definition defines the feasibility of meeting a demand with a supply. If the time difference between a particular supply availability and a particular demand requirement is insufficient to permit the transportation of a chassis from the supply location to the demand location, then that supply/demand match cannot be part of a feasible solution.

A time dependent definition of supply and demand requires a transportation model formulation of the problem to be time dependent. This means that each model formulation must apply to a stated period of time known as the planning horizon.

At the start of any modeled time period, it is necessary to account for the location of all available chassis. Any chassis available from

storage at the various ramps at the beginning of the planning horizon are considered supplies, and are assigned time attributes defined as the start of the planning horizon (i.e. time zero). Subsequent supplies are determined from scheduled train departures since chassis separated from containers are left at the ramps of departing trains. These supplies definitions consist of the number of chassis available and the time of availability assumed to be the scheduled train departure time. Chassis demands are associated with trains arriving at ramps with containers destined for further transport. These demands are defined by the number of arriving containers and the scheduled train arrival time.

Figure 4.2 extends the chassis transportation network of Figure 4.1 to include the time attribute. The cost values of the previous network have been replaced by cost-time pairs representing both the unit cost and the time required to transport chassis between the ramps. For this network, it is assumed to require 48 hours of transport time to move chassis between the Illinois Ramp and the California Ramp. Time requirements are assumed to be 2 hours for the remaining links.



An example chassis reallocation model with time attributes is illustrated in Table 4-3a. The example is based on the network

Figure 4.2 Example Network With Time Attributes

configuration of Figure 4.2 and covers a time period of 72 hours from 8:00 AM Monday to 8:00 AM Thursday. It is assumed that a supply of 5 chassis exist at each ramp at 8:00 AM Monday. The scheduled train arrivals and departures associated with Table 4-3a are given below.

	<u>CA</u>	<u>WC</u>	<u>IL</u>	<u>CH</u>	<u>NC</u>
Arrivals	TU,06:00	WE,07:00	TH,03:00	MO,22:00	TU,05:00
Departures	MO,18:00	TH,01:00	MO,17:00	TU,11:00	WE,16:00

The symbol "4" in Table 4-3a represents a time infeasibility. For example, the first cell in the table is marked as infeasible since a supply at the California Ramp Monday at 08:00 cannot reach the Chicago Ramp by Monday at 22:00. Note that as in the previous example, a cost of zero is assigned to cells that will require no chassis movements between ramps.

The first five supply values shown in Table 4-3a represent chassis available at time zero (M0,08:00) at each ramp. The subsequent supply values are counts of containers departing on scheduled trains that leave behind chassis at the given ramps. These counts are assumed to be known

TABLE 4-3a

	CH,MO 22:00	NC,TU 05:00	CA,TU 06:00	WC,WE 07:00	IL,TH 03:00	Supply
CA,MO,08:00	4	4	0	20	40	5
WC,MO,08:00	4	4	20	0	60	5
IL,MO,08:00	20	20	4	4	0	5
CH,MO,08:00	0	20	4	4	20	5
NC,MO,08:00	20	0	4	4	20	5
IL,MO,17:00	20	20	4	4	0	3
CA,MO,18:00	4	4	0	20	40	7
CH,TU,11:00	4	4	4	4	20	3
NC,WE,16:00	4	4	4	4	20	4

WC,TH,01:00	4	4	4	4	4	0
Demand	8	7	4	12	11	

or reliably estimated at time zero. For example, the supply value of 3 associated with the departure at the Illinois Ramp at 5 PM Monday (IL,MO,17:00) means that at time zero it is known or reliably predicted that 3 containers will be shipped on the train departing the Illinois Ramp at 17:00 Monday.

The demand values of Table 4-3a are counts of containers shipped on trains scheduled to arrive at the given ramps at the given times. Again these counts must be known or reliably estimated at time zero. For example, the demand value of 8 associated with the Chicago Ramp at 10:00 PM Monday (CH,MO,22:00) means that 8 containers are expected to arrive on the 22:00 Monday train at the Chicago Ramp.

The supply and demand values described above must be acquired from an external source. An information system with a function of tracking the movements and locations of containers and chassis could be utilized to obtain the required supply and demand values.

The solution to the example of Table 4-3a gives the minimum cost chassis movements shown in Table 4-3b. For example, the second entry in the table shows that 2 chassis should be moved from the supply available at the Illinois Ramp at 8:00 AM Monday to the North Chicago Ramp by 5:00 AM Tuesday. According to the network defined in Figure 4.2, the chassis would be moved by truck. The fifth entry in Table 4-3b is interpreted as the transport of 1 chassis from the California Ramp to the Illinois Ramp on the train departing the California Ramp at 6:00 PM Monday (MO,18:00).

The model assumes that there are no storage space limitations either

at the ramps or on any trains transporting chassis. Also it is assumed that chassis meeting the demands and leaving the ramps attached to containers do not return to the ramps during the planning horizon.

TABLE 4-3b

<u>From</u>	<u>To</u>	<u>Amount</u>	<u>Cost/Unit</u>	<u>Total Cost</u>
CA,MO,08:00	WC,WE,07:00	1	20	20
IL,MO,08:00	NC,TU,05:00	2	20	40
IL,MO,17:00	CH,MO,22:00	3	20	60
CA,MO,18:00	WC,WE,07:00	6	20	120
CA,MO,18:00	IL,TH,03:00	1	40	40
CH,TU,11:00	IL,TH,03:00	3	20	60
NC,WE,16:00	IL,TH,03:00	4	20	80
			Period Cost=	420

The bi-directional time based reallocation model discussed in this section will be formally defined in the sections that follow. It will be the basis of all subsequent analysis and development presented in this work.

4.3 Chassis Reallocation Model Elements

For a given period of time there are supplies and demands for chassis at each ramp. The supplies and demands are assumed to be known or reliably estimated at the beginning of the time period and may be obtained

or derived externally by existing information systems tracking the movements and locations of containers and chassis. An example of supply and demand definitions is given below.

Supplies:

1. Existing pools of chassis at each location.
2. Chassis left from departing trains.
3. Chassis shipped in on arriving trains.
4. Chassis trucked in from nearby ramps.

Demands:

1. Chassis required for containers on arriving trains.

Elements required for a model of solution include:

1. A period of business activity (day, week, etc.)
2. Train Schedules
3. Chassis stock at each ramp at beginning of period
4. Supplies and demands defined by the number of containers to be shipped on each train along with the associated train arrival or departure time as determined by train schedules.
5. Cost per chassis of meeting demands with supplies. This is the cost of meeting a demand at a particular time and location with a supply available at a particular time and location. When time constraints do not permit a particular demand to be met with a particular supply, the cost must be marked to indicate the infeasibility.

Assumptions:

1. There are no limits on chassis storage space at ramps.
2. There are no limits on space for chassis transportation on trains.
3. Chassis mated with containers on arriving trains leave the ramp and do not return during the model activity period.

A transportation model formulated according to the information given above can be used to solve for optimum chassis reallocations during the given time period.

4.4 Model Nomenclature

Elements of the proposed model can be defined as relating to planning horizon, train schedules, chassis supply and demand, and costs. Data definitions for these four areas are outlined below.

1. Planning Horizon

- Starting point in time T_0
- Total time in planning horizon T_p
- Ending time of planning horizon $T_E = T_0 + T_p$

2. Train Schedules for planning horizon, i.e., arrival and departure times at each location

- For each location j ($j=1, \dots, m$), there are n_j arrivals and p_j departures

$a_{i(j)}$ = time of arrival i ($i=1, \dots, n_j$) at location j ($j=1, \dots, m$)
 $b_{k(j)}$ = time of departure k ($k=1, \dots, p_j$) at location j
($j=1, \dots, m$)

3. Chassis supply and demand

- At time T_0 a given number of chassis exist at each location

$s_{0(j)}$ = number of existing chassis at location j at time T_0

- Each train departure from a location results in a supply of chassis being left at that time

$s_{k(j)}$ = number of chassis left by departing train at time $b_{k(j)}$

- Each train arrival at a location results in a demand for chassis at that time and location

$d_{i(j)}$ = number of chassis required by containers on train arriving at time $a_{i(j)}$

- These supplies and demands must be known or reliably forecast previous to model solution

4. Costs

- Each demand (i.e. arrival) must be matched with each supply (i.e. departure or existing chassis) to determine the cost of meeting demands with supplies

$C(d_{i(j)}, s_{k(l)})$ = cost per chassis of meeting demand $d_{i(j)}$ with supply $s_{k(l)}$,

$i = 1, n_j$; $j = 1, \dots, m$
 $k = 0, p_l$; $l = 1, \dots, m$

- If the supply is only available after the demand or the time between the availability of the supply and the demand is less than the time required to transport supply $s_{k(1)}$ to demand $d_{i(j)}$, then meeting the specified demand with the specified supply is infeasible and an extremely high cost must be specified (i.e. $C(d_{i(j)}, s_{k(1)}) = 4$)
- If demand $d_{i(j)}$ can be met with supply $s_{k(1)}$ by any means then $C(d_{i(j)}, s_{k(1)})$ can be quantified explicitly. If the supply could exist at the demand location at the time of the demand without being transported, then perhaps the cost is zero or very small. Chassis could also be transported by train or by truck from a nearby ramp if time permits. In any case, if a supply can possibly meet a demand then the actual cost must be determined and specified.

4.5 Solution Model Formulation

Using the data definitions of the previous section, a model of solution for time period T_0 through T_E may be defined as follows:

4.6 Model Complexity

The complexity of model may be expressed in terms of the size of the problems formulated from the model. Since the size of a transportation problem is proportional to the amount of resources required to solve it, there is a limit on the size of problem that is feasible to solve. This limit is defined by the available resources with respect to time and storage space.

The size of a transportation problem is often depicted in terms of the number of sources and destinations included in the problem. For example a transportation problem with 15 sources and 10 destinations may be referenced as a 15 x 10 transportation problem in order to describe its size and accordingly its complexity.

The complexity of the chassis reallocation model defined in the preceding sections of this chapter may be formulated according to the size of the transportation problems resulting from its application. Supplies in the chassis reallocation model are analogous to sources in the classical definition of the transportation model. Similarly demands in the chassis reallocation model are analogous to the destinations of the classical model. Thus further discussion of model size will be presented in terms of the number of supplies and the number of demands (i.e. 15 x 10) included in the formulated problems.

Chassis reallocation problem sizes are a function of the given planning horizon, the number of intermodal terminals in the network, and the number of scheduled arrivals and departures at each intermodal terminal. Since intermodal train arrivals correspond to chassis demands and departures correspond to chassis supply, the size of a chassis reallocation problem is driven by the number of train arrivals and

departures included in the problem. These arrivals and departures are periodic according to given train schedules. More frequent arrival and departure activity translates into larger problem sizes. Increasing the number of intermodal terminals included in a problem also increases the number of arrivals and departures. The most obvious means of increasing the number of arrivals and departures included in a chassis reallocation problem is to increase the period of time for which the problem is formulated. A mathematical formulation of problem size for the chassis reallocation model is defined as follows:

Given: T_p = total time in planning horizon
 N = number of intermodal terminals
 A_j = arrivals per unit time at terminal j
 B_j = departures per unit time at terminal j

$S = N + \sum_{j=1}^N B_j T_p$
The number of supplies for a given problem is defined by:

The first term in the above equation is simply the number of terminals since there is a possible supply of existing chassis pooled at each terminal at the start of the planning horizon. The second term represents the number of departures at each terminal during the planning horizon. The number of demands for a given problem is the number of arrivals at each terminal during the planning horizon as follows:

$$D = \sum_{j=1}^N A_j T_p$$

Table 4-4 below gives representative problem sizes for networks containing

5,10, and 15 terminals for planning horizons of 1 to 5 days. Intermodal arrivals and departures are assumed to occur at the rate of 1 per day at each terminal.

TABLE 4-4

	<u>1 DAY</u>	<u>2 DAYS</u>	<u>3 DAYS</u>	<u>4 DAYS</u>	<u>5 DAYS</u>
Ramps = 5	10 x 5	15 x 10	20 x 15	25 x 20	30 x 25
Ramps = 10	20 x 10	30 x 20	40 x 30	50 x 40	60 x 50
Ramps = 15	30 x 15	45 x 30	60 x 45	75 x 60	90 x 75

4.7 Model Implementation

The model described in the previous sections can be of practical significance in chassis logistics if implemented in a software system. Such a system could be executed periodically to provide decision support for chassis distribution management during the given period. The following chapter presents a software implementation of the model in detail.

CHAPTER 5

SOFTWARE DEVELOPMENT

5.0 Introduction

The formulation of a software system to support chassis distribution decisions is presented in this chapter. The system incorporates principles of the time-based transportation model of Chapter 4 to provide solutions to user specified models on a regular basis. The remainder of this chapter consists of a discussion of the high level design and operation of the system followed by discussions of the individual software components that comprise the system.

5.1 High Level Design and Operation

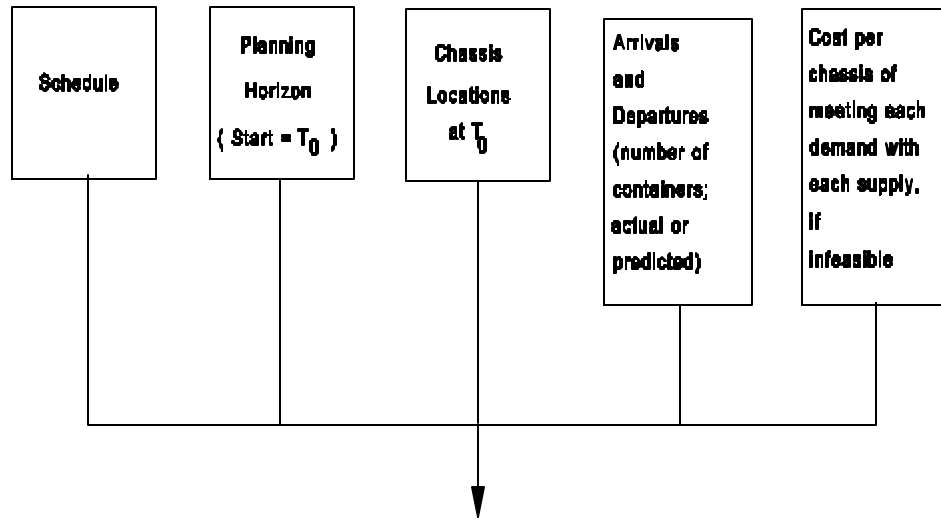
The transportation model presented in Chapter 4 provides minimum cost solutions for specific time periods. An effective software implementation of the model must provide users with timely solutions in the form of minimum cost chassis reallocations for requested planning horizons. Such a software system may be organized as shown in Figure 5.1

The heart of such a system is an optimization engine that accepts cost and supply/demand inputs and determines the minimum cost solution. The remainder of the system is concerned with determining or obtaining the correct supply, demand, and cost elements to present to the optimization engine. The text that follows is a discussion of inputs to the optimizer as shown in Figure 5.1.

1. Schedule - The major portion of chassis supply and demand determination is dependent on intermodal train schedules. Departure times are assumed to be times that chassis become available as supply.

Train arrival times are assumed to be demand times for chassis. This makes it necessary to maintain a master file of intermodal train schedules.

2. Planning Horizon - Since the model provides solutions for given periods of time, input defining a planning period must be obtained in order to determine supply and demand points from the intermodal train schedules.

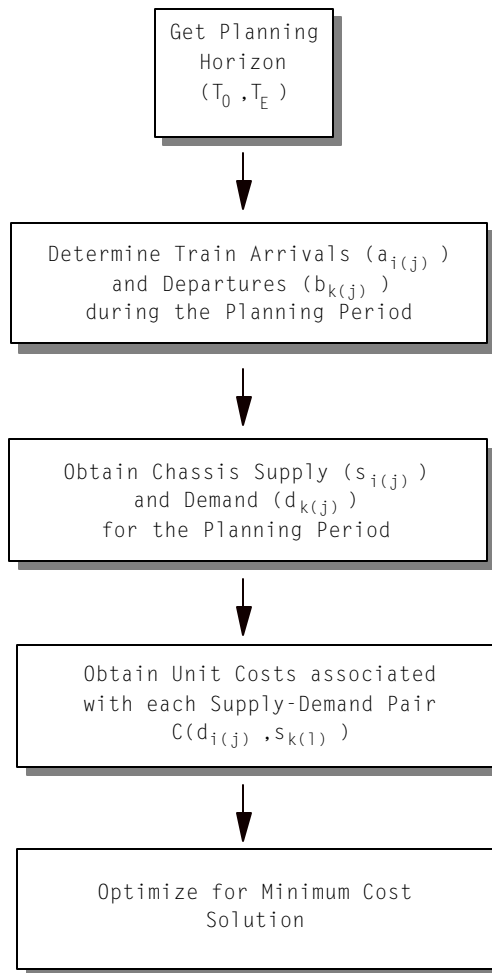


3. Initial Stock - A possible supply source exists in the form of available chassis at intermodal terminals at the beginning of each planning horizon.
4. Arrivals and Departures - Counts of containers on departing and arriving trains during the planning horizon must be specified since departing containers leave available chassis and arriving containers require available chassis. In practice some actual counts may not be available in advance and predicted counts must be used.
5. Costs - Per chassis cost of meeting each demand with each supply must be known or estimated. This includes the specification or determination of matches that are known to be infeasible.

5.1.1.1 Model Scenarios

The steps required in implementing a chassis reallocation scenario are shown in Figure 5.2. The variables referenced in Figure 5.2 conform to the nomenclature of section 4.4 of the previous Chapter defining the data elements of the mathematical solution model.

Figure 5.2 Steps in Chassis Reallocation Scenarios



Initially it is necessary to define the period of time for which a solution is desired. As noted previously this period of time is known as the planning horizon and can be specified as a starting point (T_0) and ending point (T_E) in time.

Once the planning horizon is defined it is possible to determine each arrival and departure scheduled during the planning horizon. This must be accomplished by consulting intermodal train schedules. Assuming that there are m intermodal terminals (i.e. locations) in the intermodal network with regularly scheduled intermodal train arrivals and departures, there will be n_j arrivals and p_j departures at each location j ($j=1, \dots, m$) during the planning horizon. Each scheduled arrival and departure is defined by the location (j) and time of the arrival [$a_{i(j)}$; ($i=1, \dots, n_j$), ($j=1, \dots, m$)] or departure [$b_{k(j)}$; ($k=1, \dots, p_j$), ($j=1, \dots, m$)].

Following the determination of arrivals and departures during the planning horizon is the acquisition of chassis supply and demand values for the period. One source of chassis supply are stocks of available chassis at each location ($S_{o(j)}$) at the start of the planning horizon (T_0).

The remaining chassis supplies and demands are associated with the intermodal train arrivals and departures during the planning horizon that have already been determined (i.e. $a_{i(j)}$, $b_{k(j)}$). Each train that departs an intermodal terminal carries a certain number of intermodal containers bound for subsequent destinations. Since the departing containers have been detached from chassis previous to departure, a supply of chassis equal to the number of departing containers ($S_{k(j)}$) can be associated with each departure ($b_{k(j)}$) during the planning horizon. Each train arriving at

an intermodal terminal carries a certain number of intermodal containers.

Since these containers must be mated with chassis for subsequent transport, a demand for chassis equal to the number of arriving containers ($d_{i(j)}$) can be associated with each arrival ($a_{i(j)}$) during the planning period. Thus the supply and demand values must be obtained from counts of available chassis at time zero and counts of containers destined for transport during the planning horizon.

Available chassis supply counts may be obtainable at time zero from up to date equipment inventory information. Counts of container movements during the planning horizon are likely to be more difficult to quantify since it is based on future business. In such instances it may be necessary to rely on forecasts or predictions of container movements during the planning horizon.

The final data component required for a model scenario is the transportation cost matrix representing the cost of transporting chassis between the supply and demand points during the planning horizon. Each demand ($d_{i(j)}$) defined during the planning horizon must be matched with each supply ($s_{k(j)}$) to determine a cost $[C(d_{i(j)}, s_{k(l)}); (i=1, \dots, n_j), (k=0, \dots, p_1), (j=1, \dots, m), (l=1, \dots, m)]$ of meeting the demand with the supply. This is the unit cost of transporting a chassis from the supply point (a time and location) to the demand point (also a time and location) in time for a supply chassis to be mated with a demand container upon container arrival. The assigned costs are those associated with transporting a chassis from the supply location to the demand location by whatever means is desired (truck, rail, boat etc.) during the planning horizon. Often a supply-demand match will not be feasible due to time constraints and the cost must be marked as such. Examples of

infeasible matches include those in which the time between chassis supply availability and chassis demand is less than the time required to transport the chassis from the supply location to the demand location. Infeasibility must be marked by assigning a very high cost (4) to the supply-demand match.

Upon determining the required supply, demand, and cost information as discussed previously it is left to solve the model formulated in section 4.5 of the previous chapter in order to obtain minimum cost chassis movements during the planning horizon. The model defined is a transportation model which may be solved with known solution algorithms.

5.1.2 Computerized System Design

A computerized implementation of the chassis reallocation system discussed in the previous section requires interaction between several logical system units. Those units are separable into processing units and data units. Figure 5.3 depicts the logical layout of a computerized chassis reallocation system. The system of Figure 5.3 can be described by discussing the functions of the processing units.

The schedule management unit accepts input in the form of intermodal train schedule changes in order to maintain an accurate schedule database.

The supply and demand identification unit accepts information defining the desired planning horizon and in combination with the train schedule database determines the chassis supply and demand points (time and location) for the defined planning period.

The supply points are determined from two information sources. The first source is the time associated with the start of the planning horizon (time zero) since existing pools of available chassis existing at the

intermodal terminals at time zero are a supply source. The second information source for chassis supplies is the scheduled departure times of intermodal trains during the planning horizon since departing trains

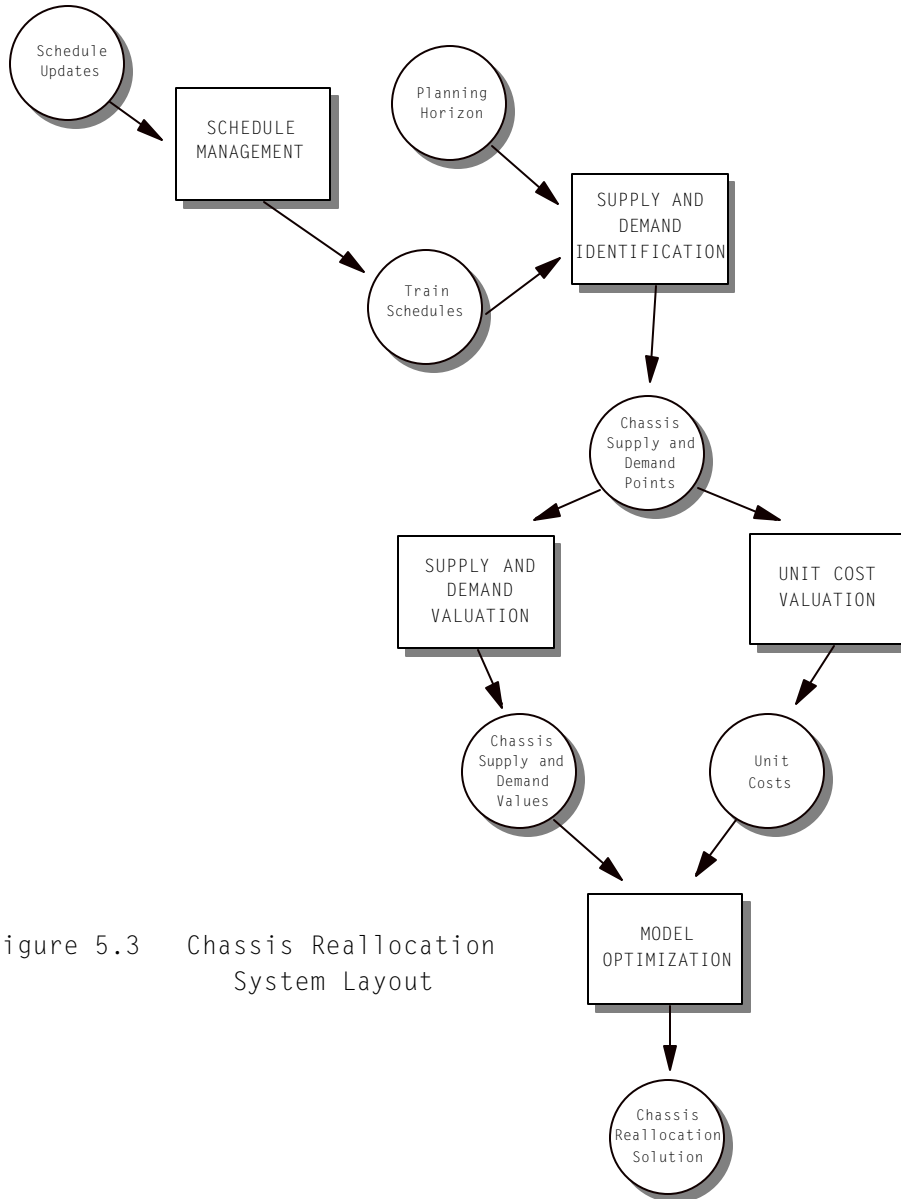


Figure 5.3 Chassis Reallocation System Layout

carry containers detached from chassis that become available upon detachment.

Chassis demand points are determined from the scheduled arrival

times of intermodal trains during the planning horizon since arriving trains carry containers that require chassis to be attached upon arrival.

Supply and demand valuation is the process of assigning numbers representing chassis availability and requirements to the supply and demand points. As noted previously these numbers correspond to container counts known or expected to exist on the intermodal trains associated with the supply and demand points.

The unit cost valuation procedure is the matching of each supply with each demand during the planning horizon to assign a cost of transporting a chassis from the supply point to the demand point. In cases where the transportation of chassis from the supply point to the demand point is not feasible due to time constraints, a very high cost must be assigned to the supply-demand match to exclude it from a feasible model solution.

After supply, demand, and cost values are determined, a model is defined and submitted to the optimization process. The solution to the defined model is the minimum cost chassis reallocation policy during the planning horizon.

5.2 Software Implementation

The implementation of a software system as described in the previous section will now be discussed and will hereafter be referenced as CHREMAN, an abbreviated name for Chassis Reallocation Manager. The objective for CHREMAN is to provide decision support for chassis fleet management on a timely basis. The operational basis for CHREMAN is a periodical execution to assist in the determination of economical chassis redistribution policies for an approaching planning period.

5.2.1 Development and Operation Environment

The initial operating platform for the CHREMAN software system is the MS-DOS operating system, version 5.0 or greater as executed on an IBM based personal computer containing an Intel 486 microprocessor with a clock speed exceeding 33 Mhz. CHREMAN should only be installed on a computer with random access memory capacity of 640 kilobytes or greater since memory size defines the size of the model that can be solved. Memory requirements are discussed in more detail in Chapter 6.

The software development environment for CHREMAN is the Turbo C++ 3.0 implementation of the C programming language for MS-DOS and is a product of Borland International, Inc. [1991].

5.2.2 CHREMAN System Programs

CHREMAN construction is based on the system design described in Section 5.1.2 and consists of six programs that interact with six data files as shown in Figure 5.4.

The CHREMAN program controls the execution of the other programs as determined by user interaction. Through execution of the CHREMAN program the user may elect to update intermodal train schedules, update estimates of time and cost requirements for transporting chassis, or execute chassis reallocation scenarios.

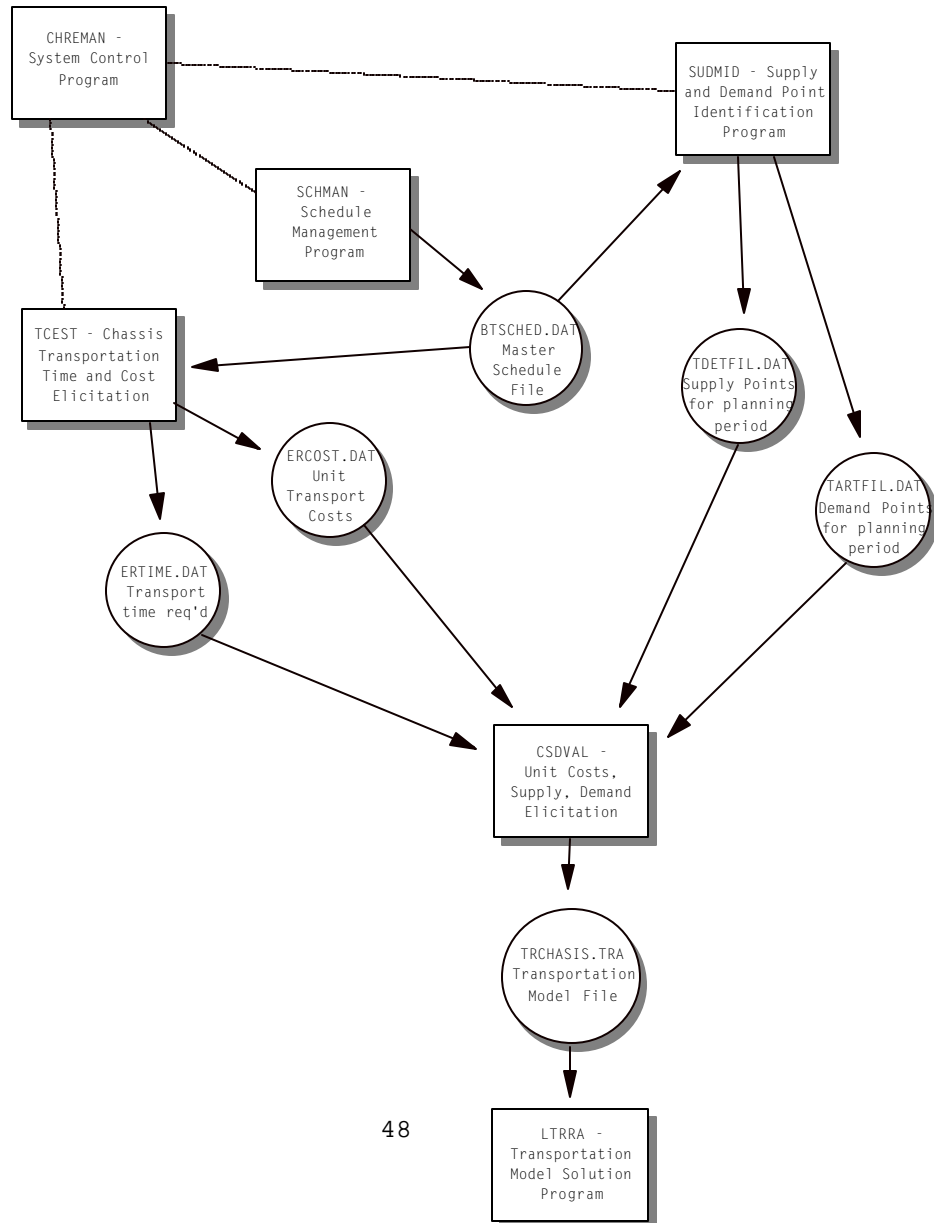
The SCHMAN program permits the user to update, view, or print intermodal train schedules. The main purpose of SCHMAN is to provide users with the ability to maintain an accurate intermodal train schedule master file (BTSCHED.DAT).

The TCEST program allows the user to maintain estimates of the time

required and the unit costs involved with transporting chassis between each terminal with scheduled intermodal service. The time and costs estimates are used to assist in unit cost determination in chassis reallocation scenarios. The time and cost estimates are maintained in the ERTIME and ERCOST data files.

The SUDMID program initiates chassis reallocation scenarios by accepting input defining the desired planning horizon and examining the

Figure 5.4 CHREMAN Software System



train schedule file to produce files containing all supply and demand points occurring in the upcoming planning horizon. The supply and demand points are written to the TDEFIL and TARTFIL data files respectively.

The CSDVAL program utilizes the information in the supply and demand point files to obtain the chassis supply and demand for the planning horizon as provided by the user. Subsequently the program estimates the chassis unit transportation costs from information in the time and cost estimation files. The user is allowed to edit the unit cost estimates before saving the defined transportation model in the transportation model file (TRCHASSIS.TRA) The LTRRA program accepts the transportation model file and solves the associated model before displaying the optimum solution. After model solution, control is returned to the CHREMAN program as selected by the user.

5.2.2.1 The CHREMAN Program

The CHREMAN program controls the execution of all other programs in the CHREMAN software system. The CHREMAN program can be considered the parent process of the system that initiates execution of the remaining programs as child processes according to user response. Upon termination of the child processes control is returned to the CHREMAN program which proceeds according to the termination code of the particular child process.

As shown in Figure 5.5, the CHREMAN program begins by presenting the user with four options corresponding to the tasks implemented in the

CHREMAN software system. When the user selects a task the program(s) associated with that task are executed as child processes in the sequence required to complete the task. In most child processes, the user has the

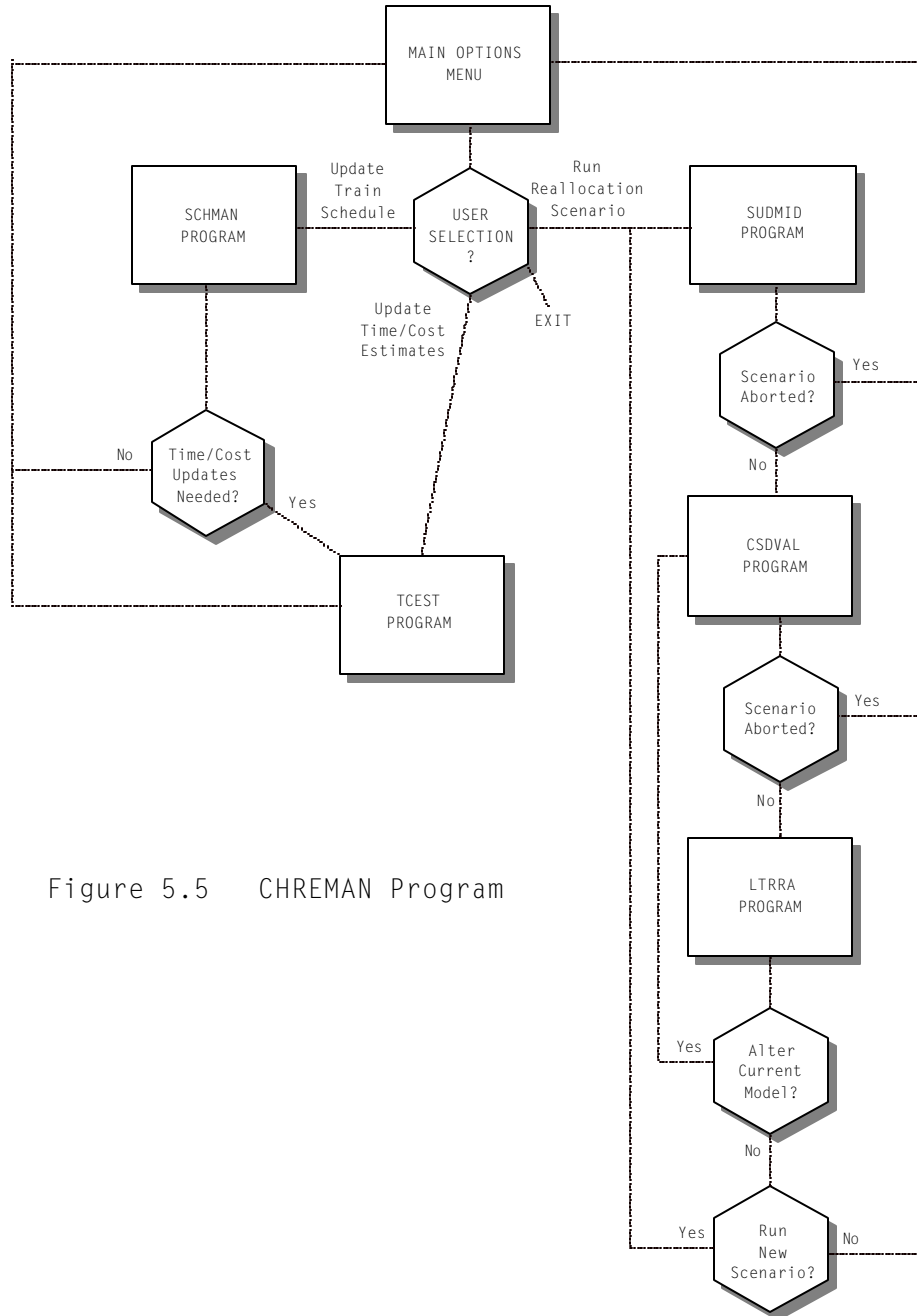


Figure 5.5 CHREMAN Program

option of aborting the process and returning to the CHREMAN main option menu. The options available to the user are 1) those associated with the

tasks of updating train schedules; 2) updating time and unit cost estimates for transporting chassis; 3) executing a reallocation scenario; and 4) exiting the CHREMAN system.

When the user chooses to update the master train schedule, the SCHMAN program is executed to permit the user to incorporate changes to the intermodal train schedule into the CHREMAN system. Certain changes to the train schedule will require the user to update time and unit costs estimates for transporting chassis between terminals. In these instances the termination code of the SCHMAN program will signal the CHREMAN program to execute the TCEST program in order for the user to update the time and cost estimates. The schedule changes that require time and unit cost updates are the addition or deletion of intermodal terminals. These changes alter the structure of the time and cost estimation matrices that must reflect the current state of intermodal terminal relationships in order to implement chassis reallocation scenarios. Examples of schedule changes that do not require updates to time and cost estimates are simple changes in arrival or departure times that do not alter the structure of the intermodal network.

Time and unit cost estimates may be updated directly at the discretion of the user by selecting the appropriate option in the main CHREMAN option menu. This selection initiates execution of the TCEST program. Time and unit cost estimates are used during chassis reallocation scenarios to estimate the unit costs for transporting chassis from supply points to demand points. Time and unit cost estimates are associated with each pair of intermodal terminals in the intermodal network and are both supplied by the user. Time estimates represent the amount of time required to transport a chassis from one terminal to

another as determined by the user. Unit cost estimates are the user's estimate of the cost associated with transporting a chassis from one terminal to another. During chassis reallocation scenarios, time and cost estimates are matched with each supply-demand pair in the planning horizon to determine 1) whether there is enough time to transport chassis from the supply point to the demand point; and 2) to identify the estimated cost of transporting a chassis from the supply point to the demand point if the match is feasible.

When the user elects to initiate a chassis reallocation scenario, the SUDMID program is executed to obtain the desired planning horizon by presenting a screen for input of the starting (T_0) and ending times (T_E) of the period. Once these are chosen, the master schedule file is used to identify each train arrival and departure during the planning horizon and write them out to disk for further processing.

If the user does not abort the SUDMID program, the CSDVAL program is executed as the next step in implementing the chassis reallocation scenario. The CSDVAL program reads all supply and demand points as determined by SUDMID and collects information from the user in order to define the required transportation model. Initially the user is prompted to input the supply and demand values that represent the counts of chassis existing at the various terminals at the start of the period or counts of containers to be carried on arriving and departing trains during the planning horizon. Following the supply and demand input, CSDVAL uses stored time and unit cost estimates to determine initial unit costs of transporting chassis between each supply-demand pair. The user may edit these costs as necessary before saving the model defined by the supply and demand counts and the unit costs. This model is the transportation model

will subsequently be solved.

The LTRRA program accepts as input the transportation model defined in the CSDVAL program and solves it to determine an optimal chassis reallocation solution for the planning horizon. The solution is displayed for perusal by the user until an option is chosen among running another reallocation scenario, refining the model for the existing scenario, or exiting back to the main CHREMAN option menu.

5.2.2.2 The SCHMAN Program

Much of the supply and demand structure in chassis reallocation scenarios is determined by intermodal train schedules. A master file of intermodal train schedules (BTSCHED.DAT) must be maintained and accessed as needed during model implementation. The basic structure of the master schedule file is defined by records identifying the intermodal terminal, the type of operation (arrival or departure), and the schedule time of the operation. The SCHMAN program represented in Figure 5.6 is menu driven and permits the user to access and alter the master schedule file.

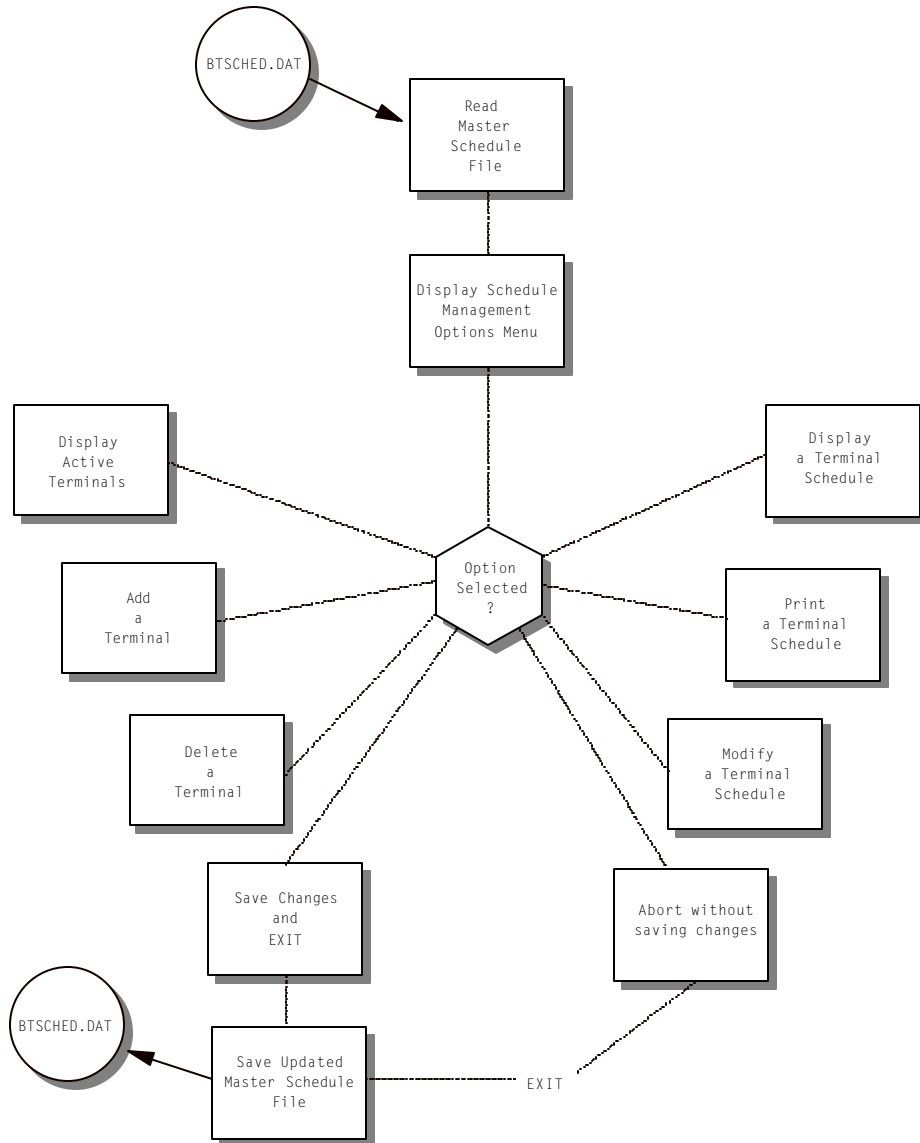
Schedule management functions permit users to list defined intermodal terminals, alter terminal schedules, add and delete terminals, or display and print terminal schedules. The user may abort the program without saving changes to the master schedule file or save changes and exit the schedule management program. Saved changes that involve the addition or deletion of intermodal terminals result in SCHMAN terminating with an exit code that instructs the CHREMAN program to execute the TCEST program.

5.2.2.3 The TCEST Program

An important feature of the CHREMAN software system is the ability

to estimate time and cost requirements associated with the transportation of chassis from one intermodal terminal to another. These time and cost values are used in chassis reallocation scenarios during execution of

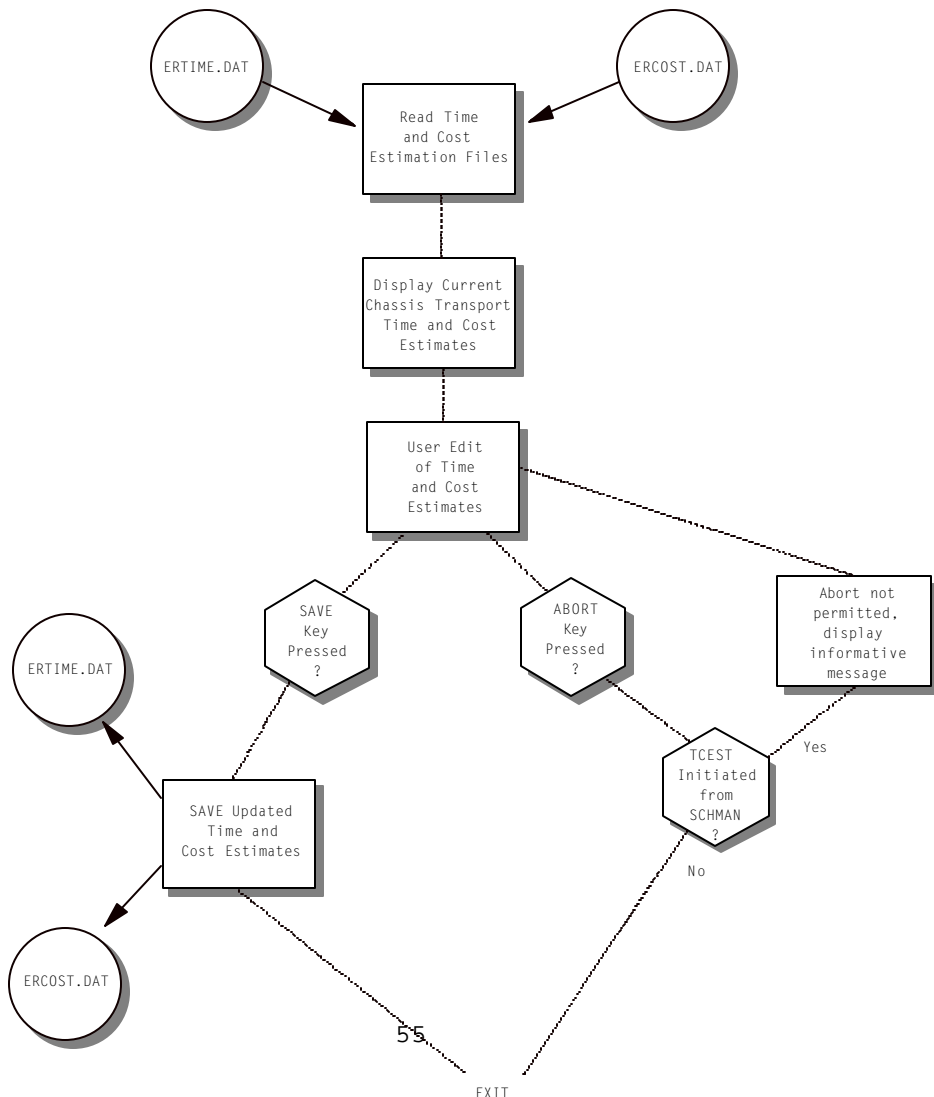
Figure 5.6 SCHMAN Program



CSDVAL to present an initial estimate of the unit cost matrix to the user.

The TCEST program represented in Figure 5.7 maintains the time and cost estimation matrices that are linked to the currently active schedule. TCEST execution may be selected from the main option menu at the discretion of the user in order to change time and/or unit transportation cost estimates. The time and cost estimation files (ERTIME.DAT and ERCOST.DAT) are linked to the currently active schedule, requiring TCEST to be executed automatically each time a schedule change is made that changes the structure of the intermodal network (i.e. adding or deleting terminals).

Figure 5.7 TCEST Program



Each of the estimation matrices is ordered by terminal pair, meaning that each matrix element represents time or cost estimate for two matched terminals. In the case of the time estimation matrix, each element represents the time required to transport a chassis from one terminal to another. Cost estimation matrix elements represent the unit cost associated with transporting a chassis from one terminal to another.

During execution of TCEST, the current time and unit cost estimation values for each terminal pair are presented to the user for editing. At any time during the edit, the user may also elect to abort the edit without saving any changes and exit. However, whenever TCEST is executed automatically as a result of schedule changes, a user abort of the edit is not permitted since time and cost estimates must be saved to correspond to the presently active schedule. TCEST returns to the CHREMAN main option menu upon termination.

5.2.2.4 The SUDMID Program

Periodically, users are expected to implement chassis reallocation scenarios to assist in chassis fleet management decisions. When this selection is made in the CHREMAN main option menu, the SUDMID program represented in Figure 5.8 is executed. SUDMID initially displays a user input screen requesting the desired planning horizon defined by starting and ending dates and times. After the user enters valid starting and ending points and elects to proceed, SUDMID identifies all supply and demand points expected during the period and writes them to output files.

A potential supply source is defined as existing stocks of chassis at each terminal at the beginning of the period. Thus SUDMID defines a supply point at time zero (T_0) of the planning horizon for every intermodal terminal in the master schedule file. In addition, every train departure during the planning horizon is a potential supply point since chassis are detached from containers and left behind at the ramps of departing trains.

SUDMID examines the master schedule file and determines all scheduled departures (time and location) during the defined planning horizon and includes them as supply points in the associated output file (TDEFIL.DAT).

Chassis demand occurs when trains arrive at intermodal terminals carrying containers that must be attached to chassis for transport to other destinations. Therefore SUDMID determines demand points by examining the master schedule and extrapolating all scheduled train

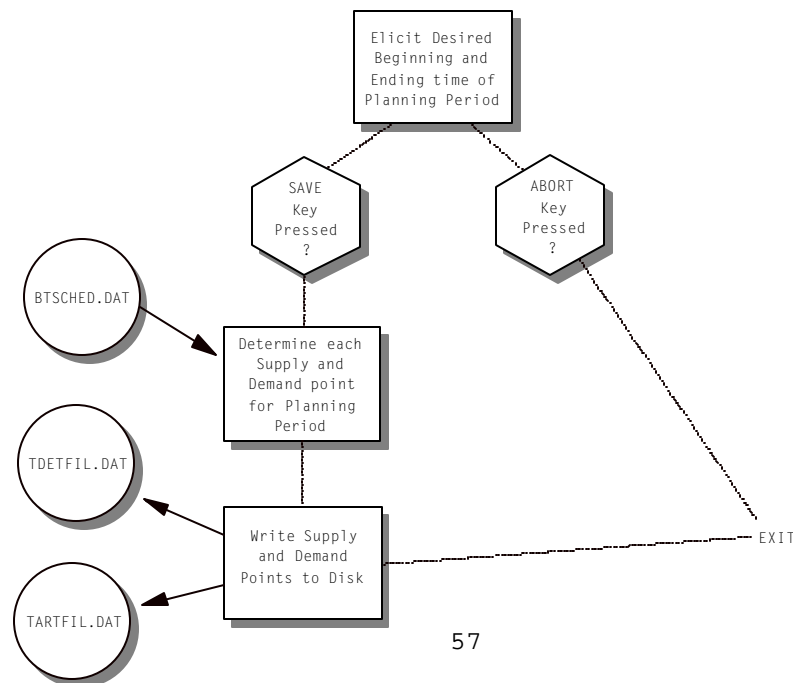


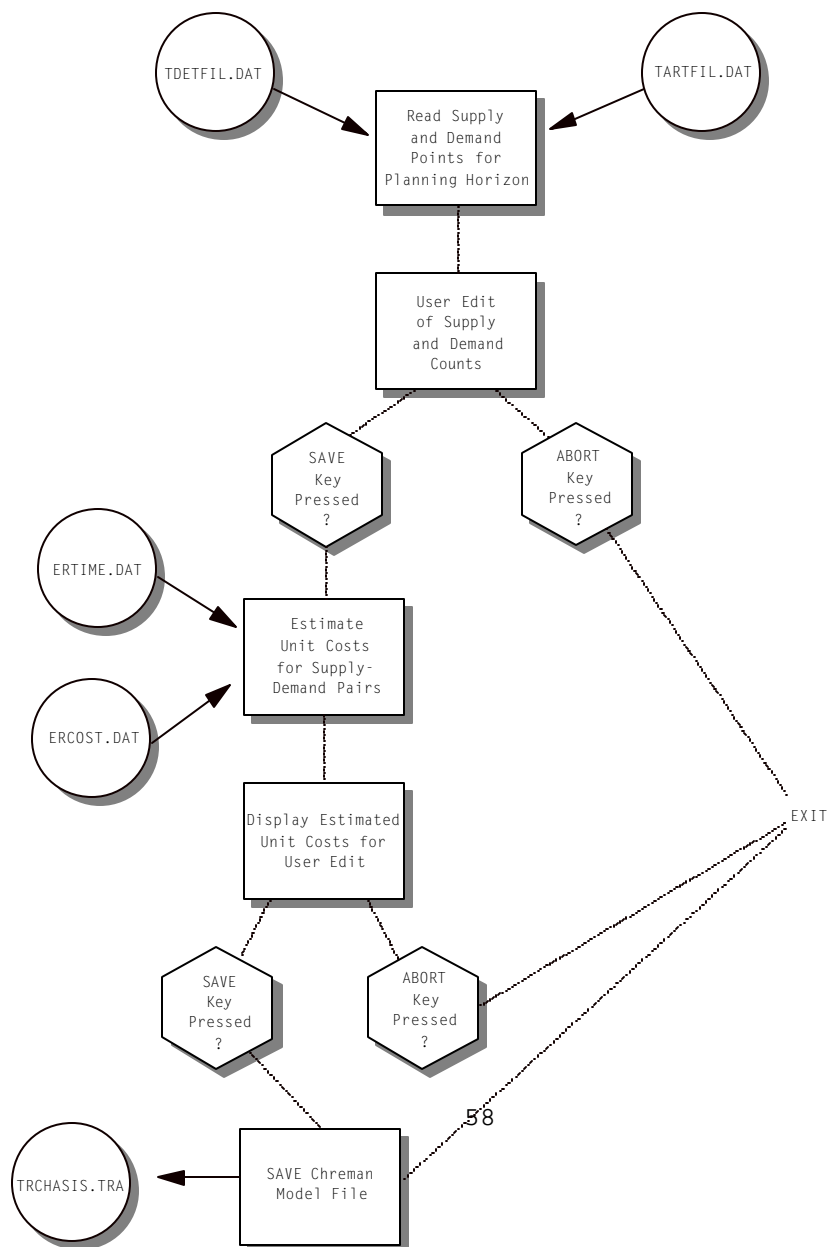
Figure 5.8 The SUDMID Program

arrivals (time and location) during the planning horizon before writing this information to the demand output file (TARTFIL.DAT).

5.2.2.5 The CSDVAL Program

The second program executed in the chassis reallocation sequence is

Figure 5.9 CSDVAL Program



the CSDVAL program outlined in Figure 5.9. CSDVAL essentially elicits and combines the final information required for a chassis reallocation model and writes the formulated model to an output file.

CSDVAL begins by reading the files created by SUDMID that define all supply and demand points during the planning horizon (TDEFIL.DAT, TARTFIL.DAT). The

supply and demand points are then displayed to the user in screens that prompt for supply and demand counts associated with each supply and demand point. Supply points are defined by type when displayed to the user. Supply type refers to 1) whether the supply is a stock of chassis available at a ramp at the beginning of the period; or 2) chassis left at ramps by departing trains. In the latter case the user is expected to supply counts of containers transported on departing trains. This equates to chassis available upon train departure.

Demand counts supplied by the user are counts of containers expected on arriving trains during the planning horizon. These counts of arriving containers are equivalent to the number of chassis required at the time and location of the scheduled intermodal train arrival.

After the user enters and saves supply and demand counts, CSDVAL matches each supply-demand pair with information in the time and cost estimation files (ERTIME.DAT, ERCOST.DAT) to develop initial unit cost estimates. These unit costs are the per chassis cost of meeting a chassis demand with a chassis supply. CSDVAL uses the time estimation matrix to estimate whether there is enough time between a demand requirement and a

supply availability to actually meet the given demand with the given supply. If there is enough time, the cost estimation matrix is used to assign an initial unit cost value to the supply-demand pair. If there is not enough time for a given demand to be met with a given supply, a very high cost is assigned to exclude the match from a feasible solution.

After CSDVAL completes the unit cost estimation process, the results are displayed on user input screens for evaluation by the user. Unit cost values for each supply-demand match during the planning period are available for alteration by the user. The display for each supply-demand match identifies the supply and demand (time and location) and displays the time between the supply availability and the demand requirement. The user is permitted to edit a feasibility indication (y,n) and a unit cost estimation supplied as a result of the CSDVAL estimation process. When the user is satisfied with the unit cost values and elects to save them, the model file (TRCHASSIS.TRA) is written to disk. It contains the complete specification of a transportation model for chassis reallocation during the given planning horizon.

5.2.2.6 The LTRRA Program

The LTRRA program represented in Figure 5.10 is an optimizer for transportation models defined in chassis reallocation scenarios. LTRRA accepts the model file (TRCHASSIS.TRA) produced by the CSDVAL program and determines the optimum solution. The LTRRA solution algorithm is based on the solution method implemented for transportation models in TORA software (see Taha [1992]). After reading the file defining the chassis reallocation model, LTRRA determines a starting solution using methods based on Vogel's Approximation method [Taha, 1992]. A screen is displayed

during this period to inform the user of the current status of the solution process. Once a starting solution is reached, a final optimum solution is reached through successive simplex-based iterations. During this period a screen is displayed that continuously updates the iteration

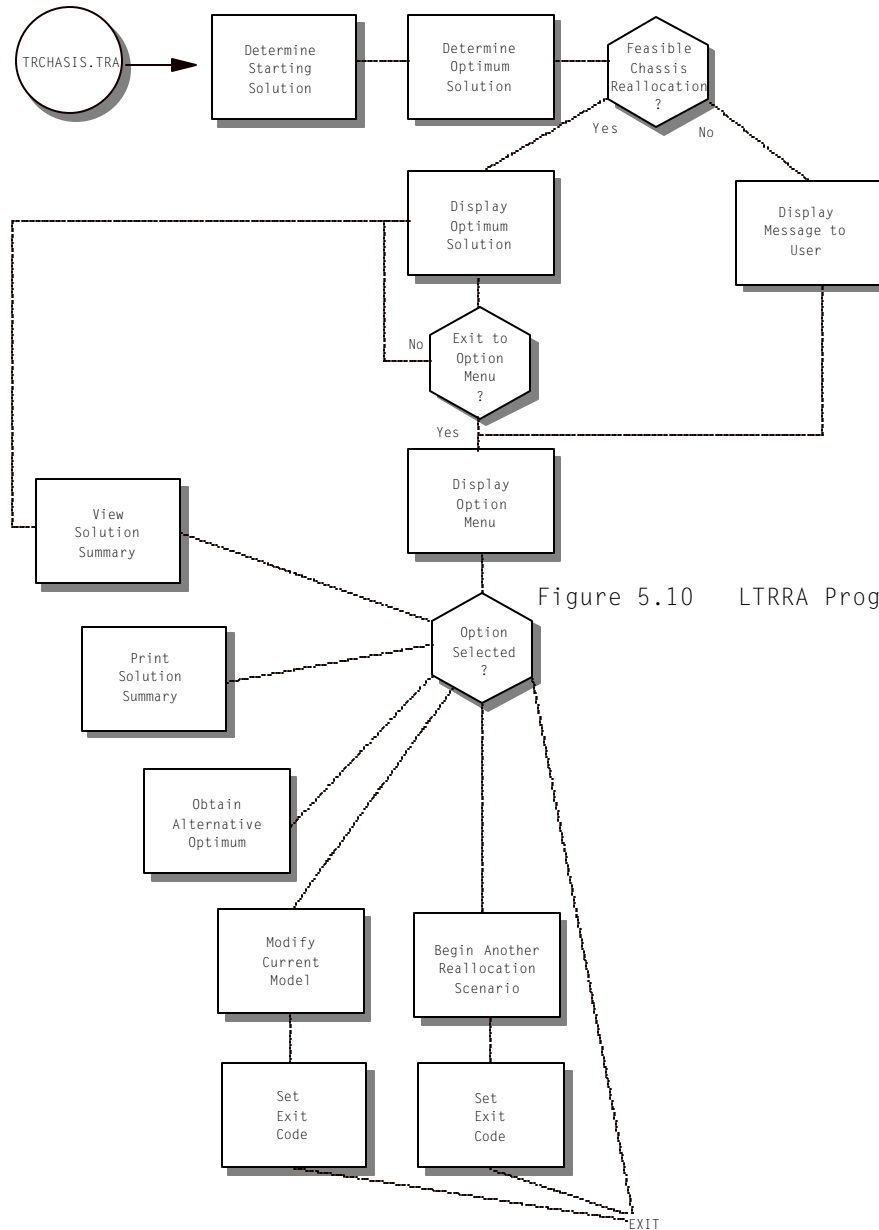


Figure 5.10 LTRRA Program

count as an indication of progress to the user.

When the optimum solution is reached the minimum cost chassis movements for the planning period are displayed for perusal by the user. It is possible that the defined chassis reallocation model has no feasible solution. This is known by the inclusion of at least one infeasible supply-demand match in the optimum solution. When the defined model has no feasible solution, a message displaying such is substituted for the model solution.

After perusing the model solution the user may elect to return to an options menu. Among the choices available in the LTRRA options menu are selections that permit the user to run another model. These selections terminate LTRRA with an exit code that returns the user to programs to either define a new model or alter the existing model. In cases where alternate minimum cost solutions exist, the user may elect to obtain the alternate solution. The options menu also has selections that permit a return to view or print the optimum solution.

5.3 Software Summary

The structure of a software system to assist in chassis fleet management decisions has been defined. The operational aspects of the CHREMAN software system demonstrate potential in applications for solving chassis redistribution problems for given time periods. The system utilizes train schedule information together with user specifications for planning horizons, container loadings, and cost estimates to solve for minimum cost chassis reallocations. Evaluation of the software system is discussed in the following chapter.

CHAPTER 6

SOFTWARE EVALUATION

6.0 Introduction

Subsequent to the successful design and development of the CHREMAN software system discussed in chapter 5, it is necessary to evaluate the effectiveness of the developed software. The objectives of this evaluation involve verification and characterization. Verification is the process of establishing the correctness of the software. In this instance the focus is to demonstrate that the software solutions are in fact the optimal transportation model solutions for the given supply, demand and cost inputs. Characterization involves the determination of computer memory requirements and execution speed of the software. For this type of software it is a function of problem size since resource requirements increase as the problem size increases.

In the evaluations that follow CHREMAN is used to generate results in designed scenarios. It is therefore expedient to establish an intermodal system into which CHREMAN is assumed to have been integrated as a support system for chassis reallocation decisions. The information that forms a basis for the intermodal system presented in this chapter was collected from a carrier operating a rail-truck intermodal system in the transportation industry. The intermodal system developed from industry information is described in detail and is followed by the evaluation of the software conducted in the framework of the described intermodal system.

6.1 Intermodal System Components

The intermodal system that is a basis for subsequent evaluation is a model developed from information collected from industry. It is very similar in structure to an existing intermodal system, differing mainly in that assumptions concerning container loadings are made where information is lacking. The intermodal system model consists of the 5 components listed below in Table 6.1 and are described in detail in the sections that follow.

TABLE 6.1 Intermodal System Components

1. PHYSICAL NETWORK
2. TRAIN SCHEDULES
3. CHASSIS TRANSPORTATION TIME ESTIMATES
4. CHASSIS TRANSPORTATION COST ESTIMATES
5. CONTAINER LOADING INFORMATION

6.1.1 Physical Network

The physical intermodal network of interest in this work is illustrated in Figure 6.1. It consists of 8 interconnected intermodal terminals stretching across the United States. Table 6.2 lists each intermodal terminal by name and abbreviation, giving the geographical locations of the terminal.

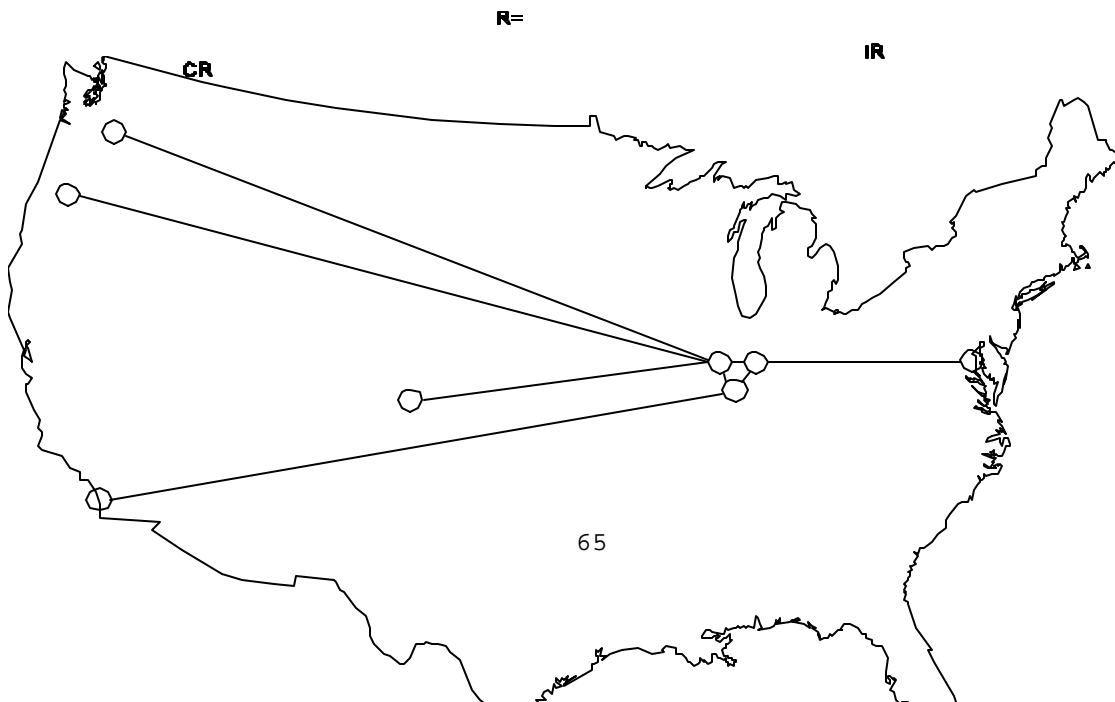
The network is connected by rail for the most part with the assumption that individual chassis may be transported between terminals at a defined cost. There are also time requirements defined for transporting chassis between terminals. The time and cost values assumed for this network are discussed in subsequent sections of this chapter.

The exception to railway linkage in the system occurs at those ramps located in the Chicago metropolitan area. Chassis movements between those

ramps may be accomplished more efficiently over the highway system by truck due to the physical proximity of the ramps.

TABLE 6.2 Intermodal Terminals

<u>Terminal Name</u>	<u>Terminal Abbreviation</u>	<u>Terminal Location</u>
California Ramp	CR	Los Angeles, CA
Portland Ramp	P=	Portland, OR
Seattle Ramp	S=	Seattle, WA
Denver Ramp	R=	Denver, CO
Chicago Ramp	C=	Chicago, IL
Illinois Ramp	IR	Chicago, IL
East Chicago Ramp	C\$	Chicago, IL
Kearny Ramp	K\$	Kearny, NJ



6.1.2 Train Schedules

As presented in previous chapters (see sections 4.3 and 4.4) much of the chassis supply and demand structure of the container based intermodal system is defined by intermodal train schedules since train departures result in chassis supply and train arrivals result in chassis demand. The intermodal train schedules used in this study are those advertised by a carrier for container business associated with the network of section 6.1.1 during 1993 and 1994. Table 6.3 shows scheduled availability and cut-off times for doublestack trains at each intermodal terminal. Note that with the exception of the Chicago ramp, there is generally one scheduled arrival and departure per day at each ramp.

6.1.3 Time Estimates

A significant feature of the CHREMAN software system is the incorporation of user-supplied time estimates in the development of initial cost matrices required for transportation model solutions. Through the use of the TCEST program (See section 5.2.2.3) the user provides estimates of the time required to transport chassis between ramps in both directions. In the intermodal system modelled in this study, time estimates are based on intermodal train schedules for terminals linked by rail and involve the difference in time between cut-off at the departing ramp and availability at the arriving ramp. In the Chicago metropolitan

area where ramps are not assumed to be linked by rail, time requirements for chassis transport between ramps is assumed to be two hours. This is based on estimates of local draymen making 2 turns between ramps in an eight hour shift, requiring 2 hours between individual ramps. For ramps that are linked indirectly, time requirements are assumed to be the summation of time requirements for direct links between the ramps.

TABLE 6.3 Doublestack Train Schedules

<u>Terminal</u>	<u>Days</u>	<u>Cut-off Times and Destination</u>	<u>Availability Times and Origin</u>
CR	SUN-WED, SAT	18:00 IR	08:00 IR
CR	THU, FRI	16:00 IR	08:00 IR
P=	TUE-SUN	03:00 C=	21:00 C=
P=	MON	-	21:00 C=
S=	SUN-SAT	19:02 C=	15:55 C=
R=	TUE-SUN	02:59 C=	07:00 C=
R=	MON	02:59 C=	-
C=	THU-TUE	11:30 P=	22:00 P=
C=	WED	11:30 P=	-
C=	SUN-SAT	21:31 S=	23:59 S=
C=	SUN	-	13:30 R=
C=	MON-SAT	00:30 R=	13:30 R=
IR	WED-SUN	17:30 CR	03:00 CR
IR	SUN	-	20:00 CR
IR	MON	17:30 CR	08:00 CR
C\$	WED-SAT	17:30 K\$	05:00 K\$
C\$	SUN	-	05:00 K\$
C\$	MON	17:30 K\$	05:00 K\$
C\$	TUE	17:00 K\$	-

K\$	WED-SAT	17:00 C\$	06:00 C\$
K\$	SUN	-	06:00 C\$
K\$	MON	17:00 C\$	06:00 C\$
K\$	TUE	17:00 C\$	-

The time required for chassis relocation is assumed to be zero within the confines of a single ramp. This is the case when chassis may be drawn from an existing stock to meet demand and no chassis transport between terminals is required. Chassis relocation time requirements for the intermodal system of this study are given in Table 6.4

Table 6.4 Chassis Relocation Time Estimates(in hours)

<u>From</u>	<u>To IR</u>	<u>To CR</u>	<u>To C=</u>	<u>To R=</u>	<u>To S=</u>	<u>To P=</u>	<u>To C\$</u>	<u>To K\$</u>
IR	0	62.5	2	32.52	67.48	59.5	2	38.5
CR	64	0	66	96.52	131.48	123.5	66	98.5
C=	2	64.5	0	30.52	65.48	57.5	2	38.5
R=	36.52	99.02	34.52	0	100	92.02	36.52	73.02
S=	78.97	141.47	76.97	107.48	0	134.47	78.97	115.47
P=	69	131.5	67	97.52	132.48	0	69	105.5
C\$	2	64.5	2	32.52	67.48	59.5	0	36.5
K\$	38	96	38	68.52	102.97	95.5	36	0

6.1.4 Cost Estimates

In conjunction with the user-supplied time estimates discussed in the previous section, the CHREMAN software system requires user estimates of unit transportation costs for chassis relocation in order to develop unit cost matrices in chassis reallocation scenarios. As with chassis

transportation time estimates, user estimates of unit chassis transportation costs are supplied using the TCEST program and are associated with each ramp pair.

As presented in section 6.1.3, the ramps in the intermodal system of this study may be linked by rail or highway, with the highway linkages assumed in the Chicago metropolitan area only. The cost of transporting a chassis between ramps that are linked by rail is assumed to be \$42.50. This cost includes \$40.00 of labor for heavy equipment operation and \$2.50 in equipment rental. The cost of transporting a chassis by truck in the Chicago metropolitan area is assumed to be \$35.00. This cost is based on the payment of \$140.00 per day to local draymen making two turns between ramps in an eight hour shift. The cost of relocating chassis that are not linked directly is assumed to be the sum of the costs of the direct links that connect the indirectly linked ramps. The cost of allocating chassis to demands requiring no inter-ramp transport is assumed to be zero. This is the case when demands at a ramp are met with available chassis at that same ramp. Unit costs associated with chassis transport are shown for each ramp pair in Table 6.5.

Table 6.5 Chassis Relocation Unit Cost Estimates(\$)

<u>From</u>	<u>To</u> IR	<u>To</u> CR	<u>To</u> C=	<u>To</u> R=	<u>To</u> S=	<u>To</u> P=	<u>To</u> C\$	<u>To</u> K\$
IR	0	42.5	35	77.5	77.5	77.5	35	77.5
CR	42.5	0	77.5	120	120	120	77.5	120
C=	35	77.5	0	42.5	42.5	42.5	35	77.5

R=	77.5	120	42.5	0	85	85	77.5	120
S=	77.5	120	42.5	85	0	85	77.5	120
P=	77.5	120	42.5	85	85	0	77.5	120
C\$	35	77.5	35	77.5	77.5	77.5	0	42.5
K\$	77.5	120	77.5	120	120	120	42.5	0

It is worthy to note that cost values used in this intermodal system are the unaltered cost values determined during execution of CHREMAN from the user-supplied chassis transport time and unit cost estimates. As discussed in section 5.2.2.5, the transportation cost matrix is estimated from user-supplied time and cost estimates and presented to the user for possible alteration previous to problem optimization. For this intermodal system the cost matrix estimated by the software strictly from the time and cost values above is assumed correct and it not altered before submission to optimization procedures.

6.1.5 Container Loadings

Information regarding actual or predicted counts of containers carried on intermodal trains is required as input to the CHREMAN system in order to complete the determination of supply and demand amounts during a planning period (See section 4.4 or section 5.2.2.5). Since actual container loadings on individual trains are not readily obtainable at the time of this study, these counts are estimated from data provided by a carrier operating in the intermodal industry. This data contains records

of individual loads for the first 3 quarters of 1993. Although this study is concerned with container (COFC) loadings in the intermodal system, trailer loadings (TOFC) are included as a proxy for COFC loadings in lanes where historical COFC traffic is light. This allows for a more realistic emulation of a fully operational system.

Each record in the data provided contains information on the history of a single intermodal load. Since the data does not contain a record of the intermodal train used in the rail portion of the journey, an estimate must be made regarding the identity of the train making the haul. This estimate is made using the historical record in combination with the given intermodal train schedules. Once a train is assigned to each load, the information can be summarized to obtain estimated counts of containers on individual trains.

With the assistance of a statistical software package with data manipulation features (The SAS System for OS/2, Release 6.10) the estimated identity of the train carrying each load is added to the record for that load and used in subsequent analysis. Each load record in the original data contains the following applicable information:

1. Origin ramp
2. Destination ramp
3. Arrival time at consignee
4. Distance (miles) from destination ramp to consignee
5. Total travel time on rail
6. Total waiting time at ramps

The algorithm used to estimate the scheduled cut-off time of the train carrying the load is illustrated in Figure 6.2. It involves working backwards in time from the given arrival time at the consignee to obtain an estimate of the arrival time of the load at the origin ramp.

Beginning with the consignee arrival time, the time that the load

departed the destination ramp is estimated using the given mileage between the destination ramp and the consignee. This transit time is estimated using an industry methodology involving an assumption of 45 miles per hour average driving speed along with time allowances for meals, rest, fueling, and inspections. Table 6.6 shows the assumed time allowances for specific mileages used in calculating transit times. The destination ramp arrival time is estimated from the destination ramp departure time less half of the total waiting time at destination and origin ramps. Origin ramp

Figure 6.2 Train Assignment Estimation Algorithm

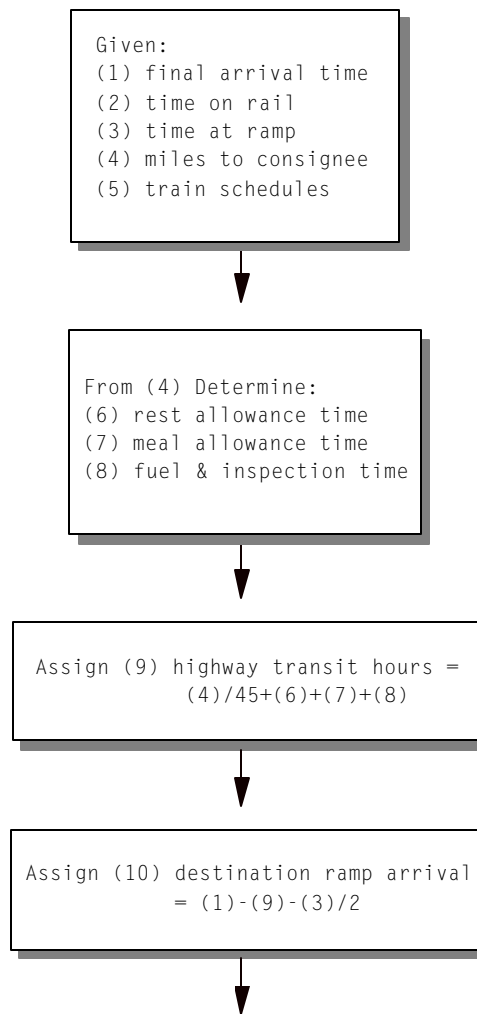


TABLE 6.6 Transit Time Allowances (in hours)

<u>Mileage</u>	<u>Meal Time</u>	<u>Fueling and Inspection</u>	<u>Rests and Breaks</u>
100	0	0.75	0
200	0	0.75	0
300	0	0.75	0
400	1	0.75	0
500	1	0.75	8
600	1	0.75	8
700	2	1.00	8
800	2	1.25	8
900	2	1.25	8
1000	3	1.25	16
1100	3	1.25	16
1200	3	1.50	16
1300	3	1.50	16

1400	4	1.50	24
1500	4	1.50	24
1600	4	2.00	24
1700	4	2.00	24
1800	5	2.00	24
1900	5	2.25	32
2000	5	2.50	32

departure time is obtained by subtracting the total time on rail from the estimated destination ramp arrival time. The origin ramp arrival time is then estimated as the origin ramp departure time less the remaining half of the total ramp waiting time.

Once the estimated arrival time of the load at the origin ramp is determined, the load is assumed to have been transported on the next departing train. This determination is made by examining the scheduled cut-off times for trains departing the origin ramp. When the cut-off time of the departing train is determined, the scheduled availability of the load at the destination ramp is also known and both values are included in the output data record for that load.

Subsequent to the assignment of loads to scheduled trains, counts of containers on individual trains are available by summarizing the records by ramp pairings and day of week. Results of this analysis lead to the assignment of distributions of departing containers at each ramp for every scheduled departure during the week. The departure distributions for this system are all assumed discrete uniform as defined by the minimum and maximum container loads estimated for each departure at each ramp during the period of time covered by the given data. These departure distributions are given in Table 6.7 and are used exclusively in the

intermodal system described in this study. Estimated container arrival distributions are not needed since these are known from the departure distributions and the train schedules.

6.2 Verification

An important step in the software development process involves determining whether the software performs according to an established specification. This stage may be called verification and it can be accomplished by developing a test plan that can be used in investigating the correctness of the software. In the case of CHREMAN software it is important to establish that 1) supply and demand points are identified correctly with respect to times and locations; and 2) the solutions to the formulated transportation models are indeed the optimal solutions

TABLE 6.7 Parameters(min,max) of Discrete Uniform Departure Distributions

<u>Orig.</u>	<u>Dest.</u>	<u>SUN</u>	<u>MON</u>	<u>TUE</u>	<u>WED</u>	<u>THU</u>	<u>FRI</u>	<u>SAT</u>
IR	CR	(2,22)	(1,19)	(1,17)	(1,10)	(1,10)	(1,25)	(1,30)
CR	IR	(1,22)	(1,6)	(1,10)	(1,8)	(2,12)	(1,28)	(1,29)
C=	R=	-	(1,7)	(1,2)	(1,5)	(3,5)	(1,3)	(1,7)
C=	S=	(3,16)	(1,10)	(3,7)	(1,3)	(1,7)	(5,18)	(1,13)
C=	P=	(2,8)	(1,7)	(1,10)	(1,4)	(1,1)	(4,11)	(2,10)
R=	C=	(1,3)	(1,6)	(1,2)	(1,4)	(1,3)	(2,5)	(1,7)
S=	C=	(1,11)	(3,6)	(2,3)	(1,8)	(5,16)	(1,14)	(2,18)
P=	C=	(1,11)	-	(2,13)	(1,9)	(3,9)	(2,16)	(1,14)
C\$	K\$	-	(1,22)	(2,14)	(1,15)	(4,10)	(1,3)	(3,8)
K\$	C\$	-	(1,23)	(4,9)	(3,9)	(2,12)	(2,3)	(5,9)

associated with the given supplies, demands, and unit costs.

Investigation of CHREMAN with respect to the verification objectives can be accomplished by implementing CHREMAN in the intermodal system described in section 6.1. Both objectives can be studied simultaneously since objective 1 can be considered in scenarios designed to examine objective 2. A summary explanation of the scenarios formulated for the verification process is given in Table 6.8.

For each of the 8 scenarios presented a planning horizon of 3 days is used and chosen arbitrarily to begin on a Sunday at 12:00 am and extend to Tuesday at 11:59 pm. The relatively small problem size is employed to facilitate understanding of the scenarios and permit examination of complete solution sets. Each of the results can be shown to be consistent with those associated with larger problem sizes.

TABLE 6.8 Verification Scenarios

<u>Scenario</u>	<u>Explanation</u>
1	Null Problem, Supplies=Demands=Cost=0
2	Supply > Demand, no chassis relocations required
3	Supply > Demand, chassis relocations required
4	Supply > Demand, solution infeasible
5	Supply = Demand, no chassis relocations required
6	Supply = Demand, chassis relocations required
7	Supply = Demand, solution infeasible
8	Supply < Demand, solution infeasible

6.2.1 Verification Results

Table 6.9 is the CHREMAN output listing for the null problem, where the null problem is defined as the problem that results from only the planning horizon being specified and no supply, demand, or cost data actually being entered. CHREMAN automatically supplies zeros for those inputs ignored by the user. Although null problems have no practical implications in chassis reallocation scenarios, it is good software

practice to produce results that are consistent even with unexpected situations. Notice in Table 6.9 that the total reallocation cost is zero and that no demands are resolved from the listed supplies. The correctness of the supply points identified by CHREMAN can be verified by referencing Table 6.3 with the given planning horizon and considering that an existing supply point is assumed at time zero at each of the ramps.

Results for the chassis reallocation problem considered in scenario 2 are shown in Table 6.10. In scenario 2 it is assumed that 5 chassis exist at each ramp at time zero and that only demands for 2 chassis occur at each ramp during the planning horizon. The results of Table 6.3 are optimal and equal to zero since the unit cost of chassis relocation for demands met at a ramp by existing chassis stock is assumed to be zero.

Scenario 3 is similar to scenario 2 with the exception that a demand

TABLE 6.9 Scenario 1 Output

```

Chassis Movement Optimization
Date: Tue Jun 20 17:19:04 1995

                                OPTIMUM SOLUTION
                                NOTE: No Unit Relocations Required

Title:      Chassis Allocation Problem
Size:(34 x 27)
Final iteration no: 10
Total cost = 0.0000
-----
Supply Source      Demand At      Units  Cost/Unit  Rte.Cost
-----
IR, Su Jun 25 1995 00:00
IR, Su Jun 25 1995 17:30
IR, Mo Jun 26 1995 17:30
IR, Tu Jun 27 1995 17:30
CR, Su Jun 25 1995 00:00
CR, Su Jun 25 1995 18:00
CR, Mo Jun 26 1995 18:00
CR, Tu Jun 27 1995 18:00
C=, Su Jun 25 1995 00:00
C=, Su Jun 25 1995 11:30
C=, Su Jun 25 1995 21:31
C=, Mo Jun 26 1995 00:30
C=, Mo Jun 26 1995 11:30
C=, Mo Jun 26 1995 21:31
C=, Tu Jun 27 1995 00:30
C=, Tu Jun 27 1995 11:30
C=, Tu Jun 27 1995 21:31
R=, Su Jun 25 1995 00:00
R=, Su Jun 25 1995 02:59
R=, Mo Jun 26 1995 02:59
R=, Tu Jun 27 1995 02:59
S=, Su Jun 25 1995 00:00
S=, Su Jun 25 1995 19:02
S=, Mo Jun 26 1995 19:02
S=, Tu Jun 27 1995 19:02
P=, Su Jun 25 1995 00:00
P=, Su Jun 25 1995 03:00
P=, Tu Jun 27 1995 03:00
C$, Su Jun 25 1995 00:00
C$, Mo Jun 26 1995 17:30
C$, Tu Jun 27 1995 17:30
K$, Su Jun 25 1995 00:00
K$, Mo Jun 26 1995 17:00
K$, Tu Jun 27 1995 17:00

```

for 7 chassis at IR on Sunday 3:00 am is assumed. Since there only 5

chassis at IR at time zero and no additional supply sources (departures) at IR between time zero (Sunday 12:00 am) and 3:00 am Sunday, a chassis relocation is required to meet the demand at IR. As seen in Table 6.11 the demand at IR is met by transporting 3 chassis from the time zero chassis pool at C= to meet the 3:00 am Sunday arrival. This is possible because the time required for chassis transport between IR and C= is specified as 2 hours in Table 6.4 at a cost of \$35.00 per chassis specified in Table 6.5.

Scenario 4 results from increasing the scenario 3 demand of 7 chassis at IR on Sunday 3:00 am to 11 chassis. This results in an infeasible solution since there is an insufficient supply of chassis available for transport within the required time frame to meet the demand

TABLE 6.10 Scenario 2 Output

Chassis Movement Optimization
Date: Tue Jun 20 21:18:51 1995

OPTIMUM SOLUTION

NOTE: No Unit Relocations Required

Title: Chassis Allocation Problem
Size:(34 x 28)
Final iteration no: 15
Total cost = 0.0000

Supply Source	Demand At	Units	Cost/Unit	Rte.Cost
IR, Su Jun 25 1995 00:00	IR, Su Jun 25 1995 03:00	1	0.00	0.00
	IR, Su Jun 25 1995 20:00	1	0.00	0.00
IR, Su Jun 25 1995 17:30				
IR, Mo Jun 26 1995 17:30				
IR, Tu Jun 27 1995 17:30				
CR, Su Jun 25 1995 00:00	CR, Su Jun 25 1995 08:00	1	0.00	0.00
	CR, Mo Jun 26 1995 08:00	1	0.00	0.00
CR, Su Jun 25 1995 18:00				
CR, Mo Jun 26 1995 18:00				
CR, Tu Jun 27 1995 18:00				
C=, Su Jun 25 1995 00:00	C=, Su Jun 25 1995 13:30	1	0.00	0.00
	C=, Su Jun 25 1995 22:00	1	0.00	0.00
C=, Su Jun 25 1995 11:30				
C=, Su Jun 25 1995 21:31				
C=, Mo Jun 26 1995 00:30				
C=, Mo Jun 26 1995 11:30				
C=, Mo Jun 26 1995 21:31				
C=, Tu Jun 27 1995 00:30				
C=, Tu Jun 27 1995 11:30				
C=, Tu Jun 27 1995 21:31				
R=, Su Jun 25 1995 00:00	R=, Su Jun 25 1995 07:00	1	0.00	0.00
	R=, Tu Jun 27 1995 07:00	1	0.00	0.00
R=, Su Jun 25 1995 02:59				
R=, Mo Jun 26 1995 02:59				
R=, Tu Jun 27 1995 02:59				
S=, Su Jun 25 1995 00:00	S=, Su Jun 25 1995 15:55	1	0.00	0.00
	S=, Mo Jun 26 1995 15:55	1	0.00	0.00
S=, Su Jun 25 1995 19:02				
S=, Mo Jun 26 1995 19:02				
S=, Tu Jun 27 1995 19:02				
P=, Su Jun 25 1995 00:00	P=, Su Jun 25 1995 21:00	1	0.00	0.00
	P=, Mo Jun 26 1995 21:00	1	0.00	0.00
P=, Su Jun 25 1995 03:00				
P=, Tu Jun 27 1995 03:00				
C\$, Su Jun 25 1995 00:00	C\$, Su Jun 25 1995 05:00	1	0.00	0.00
	C\$, Mo Jun 26 1995 05:00	1	0.00	0.00
C\$, Mo Jun 26 1995 17:30				
C\$, Tu Jun 27 1995 17:30				
K\$, Su Jun 25 1995 00:00	K\$, Su Jun 25 1995 06:00	1	0.00	0.00
	K\$, Mo Jun 26 1995 06:00	1	0.00	0.00
K\$, Mo Jun 26 1995 17:00				
K\$, Tu Jun 27 1995 17:00				

at IR. Actually a more accurate statement is that the chassis supply is insufficient when considered in concert with all other demands. In other words, the only chassis that can be moved to IR in a 3 hour time frame are those at C= and C\$. Since there are also demands at C= and C\$ in this scenario, additional transport of chassis from those ramps would result in shortages at those ramps. Infeasible solutions are indicated to the user by the display of the following message at the conclusion of attempts at optimization:

NO FEASIBLE SOLUTION - Supply Location and Timing is insufficient
to meet Demand Locations and Times
Press Any Key ...

TABLE 6.11 Scenario 3 Output

Chassis Movement Optimization
Date: Tue Jun 20 21:37:06 1995

OPTIMUM SOLUTION

Title: Chassis Allocation Problem
Size:(34 x 28)
Final iteration no: 15
Total cost = 105.0000

Supply Source	Demand At	Units	Cost/Unit	Rte.Cost
IR, Su Jun 25 1995 00:00	IR, Su Jun 25 1995 03:00	4	0.00	0.00
	IR, Su Jun 25 1995 20:00	1	0.00	0.00
IR, Su Jun 25 1995 17:30				
IR, Mo Jun 26 1995 17:30				
IR, Tu Jun 27 1995 17:30				
CR, Su Jun 25 1995 00:00	CR, Su Jun 25 1995 08:00	1	0.00	0.00
	CR, Mo Jun 26 1995 08:00	1	0.00	0.00
CR, Su Jun 25 1995 18:00				
CR, Mo Jun 26 1995 18:00				
CR, Tu Jun 27 1995 18:00				
C=, Su Jun 25 1995 00:00	IR, Su Jun 25 1995 03:00	3	35.00	105.00
	C=, Su Jun 25 1995 13:30	1	0.00	0.00
	C=, Su Jun 25 1995 22:00	1	0.00	0.00
C=, Su Jun 25 1995 11:30				
C=, Su Jun 25 1995 21:31				
C=, Mo Jun 26 1995 00:30				
C=, Mo Jun 26 1995 11:30				
C=, Mo Jun 26 1995 21:31				
C=, Tu Jun 27 1995 00:30				
C=, Tu Jun 27 1995 11:30				
C=, Tu Jun 27 1995 21:31				
R=, Su Jun 25 1995 00:00	R=, Su Jun 25 1995 07:00	1	0.00	0.00
	R=, Tu Jun 27 1995 07:00	1	0.00	0.00
R=, Su Jun 25 1995 02:59				
R=, Mo Jun 26 1995 02:59				
R=, Tu Jun 27 1995 02:59				
S=, Su Jun 25 1995 00:00	S=, Su Jun 25 1995 15:55	1	0.00	0.00
	S=, Mo Jun 26 1995 15:55	1	0.00	0.00
S=, Su Jun 25 1995 19:02				
S=, Mo Jun 26 1995 19:02				
S=, Tu Jun 27 1995 19:02				
P=, Su Jun 25 1995 00:00	P=, Su Jun 25 1995 21:00	1	0.00	0.00
	P=, Mo Jun 26 1995 21:00	1	0.00	0.00
P=, Su Jun 25 1995 03:00				
P=, Tu Jun 27 1995 03:00				
C\$, Su Jun 25 1995 00:00	C\$, Su Jun 25 1995 05:00	1	0.00	0.00
	C\$, Mo Jun 26 1995 05:00	1	0.00	0.00
C\$, Mo Jun 26 1995 17:30				
C\$, Tu Jun 27 1995 17:30				
K\$, Su Jun 25 1995 00:00	K\$, Su Jun 25 1995 06:00	1	0.00	0.00
	K\$, Mo Jun 26 1995 06:00	1	0.00	0.00
K\$, Mo Jun 26 1995 17:00				
K\$, Tu Jun 27 1995 17:00				

Scenario 5 is similar to scenario 2 except that additional chassis

demands have been included so that total chassis supply is equal to total chassis demand. In this scenario, every possible demand is set to one chassis or greater so that all possible demand points are included in the CHREMAN output of Table 6.12. These demands may be referenced with the train schedules of Table 6.3 to verify the correctness of demand point determination. As expected, no chassis relocation is required in scenario 5 since sufficient chassis supply is available at time zero to meet demands during the planning period.

The chassis supply of scenario 5 can be adjusted to demonstrate a scenario when total chassis supply equals total chassis demand, but a

TABLE 6.12 Scenario 5 Output

Chassis Movement Optimization
Date: Tue Jun 20 23:27:28 1995

OPTIMUM SOLUTION

NOTE: No Unit Relocations Required

Title: Chassis Allocation Problem
Size: (34 x 27)
Final iteration no: 3
Total cost = 0.0000

Supply Source	Demand At	Units	Cost/Unit	Rte.Cost
IR, Su Jun 25 1995 00:00	IR, Su Jun 25 1995 03:00	2	0.00	0.00
	IR, Su Jun 25 1995 20:00	2	0.00	0.00
	IR, Mo Jun 26 1995 08:00	1	0.00	0.00
IR, Su Jun 25 1995 17:30				
IR, Mo Jun 26 1995 17:30				
IR, Tu Jun 27 1995 17:30				
CR, Su Jun 25 1995 00:00	CR, Su Jun 25 1995 08:00	2	0.00	0.00
	CR, Mo Jun 26 1995 08:00	2	0.00	0.00
	CR, Tu Jun 27 1995 08:00	1	0.00	0.00
CR, Su Jun 25 1995 18:00				
CR, Mo Jun 26 1995 18:00				
CR, Tu Jun 27 1995 18:00				
C=, Su Jun 25 1995 00:00	C=, Su Jun 25 1995 13:30	1	0.00	0.00
	C=, Su Jun 25 1995 22:00	1	0.00	0.00
	C=, Su Jun 25 1995 23:59	1	0.00	0.00
	C=, Mo Jun 26 1995 13:30	1	0.00	0.00
	C=, Mo Jun 26 1995 22:00	1	0.00	0.00
	C=, Mo Jun 26 1995 23:59	1	0.00	0.00
	C=, Tu Jun 27 1995 13:30	1	0.00	0.00
	C=, Tu Jun 27 1995 22:00	1	0.00	0.00
	C=, Tu Jun 27 1995 23:59	1	0.00	0.00
C=, Su Jun 25 1995 11:30				
C=, Su Jun 25 1995 21:31				
C=, Mo Jun 26 1995 00:30				
C=, Mo Jun 26 1995 11:30				
C=, Mo Jun 26 1995 21:31				
C=, Tu Jun 27 1995 00:30				
C=, Tu Jun 27 1995 11:30				
C=, Tu Jun 27 1995 21:31				
R=, Su Jun 25 1995 00:00	R=, Su Jun 25 1995 07:00	4	0.00	0.00
	R=, Tu Jun 27 1995 07:00	1	0.00	0.00
R=, Su Jun 25 1995 02:59				
R=, Mo Jun 26 1995 02:59				
R=, Tu Jun 27 1995 02:59				
S=, Su Jun 25 1995 00:00	S=, Su Jun 25 1995 15:55	2	0.00	0.00
	S=, Mo Jun 26 1995 15:55	2	0.00	0.00
	S=, Tu Jun 27 1995 15:55	1	0.00	0.00
S=, Su Jun 25 1995 19:02				
S=, Mo Jun 26 1995 19:02				
S=, Tu Jun 27 1995 19:02				
P=, Su Jun 25 1995 00:00	P=, Su Jun 25 1995 21:00	2	0.00	0.00
	P=, Mo Jun 26 1995 21:00	2	0.00	0.00
	P=, Tu Jun 27 1995 21:00	1	0.00	0.00
P=, Su Jun 25 1995 03:00				
P=, Tu Jun 27 1995 03:00				
C\$, Su Jun 25 1995 00:00	C\$, Su Jun 25 1995 05:00	4	0.00	0.00
	C\$, Mo Jun 26 1995 05:00	1	0.00	0.00
C\$, Mo Jun 26 1995 17:30				
C\$, Tu Jun 27 1995 17:30				
K\$, Su Jun 25 1995 00:00	K\$, Su Jun 25 1995 06:00	4	0.00	0.00
	K\$, Mo Jun 26 1995 06:00	1	0.00	0.00
K\$, Mo Jun 26 1995 17:00				
K\$, Tu Jun 27 1995 17:00				

solution requires some chassis relocation. For scenario 6 chassis supply at C= was reduced to 8 chassis at time zero so that meeting the total demand of 9 chassis at C= during the planning period requires chassis relocation. Total chassis supply for scenario 6 is set equal to chassis demand by including a departure at R= on Sunday at 2:59 am. As shown in the CHREMAN output for scenario 6 in Table 6.13 a chassis relocation by rail is required in the optimum solution.

A scenario with total chassis supply equal to total chassis demand is also presented in scenario 7. The chassis supply in scenario 6 at time

TABLE 6.13 Scenario 6 Output

Chassis Movement Optimization
Date: Tue Jun 20 23:28:50 1995

OPTIMUM SOLUTION

Title: Chassis Allocation Problem
Size:(34 x 27)
Final iteration no: 12
Total cost = 42.5000

Supply Source	Demand At	Units	Cost/Unit	Rte.Cost
IR, Su Jun 25 1995 00:00	IR, Su Jun 25 1995 03:00	2	0.00	0.00
	IR, Su Jun 25 1995 20:00	2	0.00	0.00
	IR, Mo Jun 26 1995 08:00	1	0.00	0.00
IR, Su Jun 25 1995 17:30				
IR, Mo Jun 26 1995 17:30				
IR, Tu Jun 27 1995 17:30				
CR, Su Jun 25 1995 00:00	CR, Su Jun 25 1995 08:00	2	0.00	0.00
	CR, Mo Jun 26 1995 08:00	2	0.00	0.00
	CR, Tu Jun 27 1995 08:00	1	0.00	0.00
CR, Su Jun 25 1995 18:00				
CR, Mo Jun 26 1995 18:00				
CR, Tu Jun 27 1995 18:00				
C=, Su Jun 25 1995 00:00	C=, Su Jun 25 1995 13:30	1	0.00	0.00
	C=, Su Jun 25 1995 22:00	1	0.00	0.00
	C=, Su Jun 25 1995 23:59	1	0.00	0.00
	C=, Mo Jun 26 1995 13:30	1	0.00	0.00
	C=, Mo Jun 26 1995 23:59	1	0.00	0.00
	C=, Tu Jun 27 1995 13:30	1	0.00	0.00
	C=, Tu Jun 27 1995 22:00	1	0.00	0.00
	C=, Tu Jun 27 1995 23:59	1	0.00	0.00
C=, Su Jun 25 1995 11:30				
C=, Su Jun 25 1995 21:31				
C=, Mo Jun 26 1995 00:30				
C=, Mo Jun 26 1995 11:30				
C=, Mo Jun 26 1995 21:31				
C=, Tu Jun 27 1995 00:30				
C=, Tu Jun 27 1995 11:30				
C=, Tu Jun 27 1995 21:31				
R=, Su Jun 25 1995 00:00	R=, Su Jun 25 1995 07:00	4	0.00	0.00
	R=, Tu Jun 27 1995 07:00	1	0.00	0.00
R=, Su Jun 25 1995 02:59	C=, Mo Jun 26 1995 22:00	1	42.50	42.50
R=, Mo Jun 26 1995 02:59				
R=, Tu Jun 27 1995 02:59				
S=, Su Jun 25 1995 00:00	S=, Su Jun 25 1995 15:55	2	0.00	0.00
	S=, Mo Jun 26 1995 15:55	2	0.00	0.00
	S=, Tu Jun 27 1995 15:55	1	0.00	0.00
S=, Su Jun 25 1995 19:02				
S=, Mo Jun 26 1995 19:02				
S=, Tu Jun 27 1995 19:02				
P=, Su Jun 25 1995 00:00	P=, Su Jun 25 1995 21:00	2	0.00	0.00
	P=, Mo Jun 26 1995 21:00	2	0.00	0.00
	P=, Tu Jun 27 1995 21:00	1	0.00	0.00
P=, Su Jun 25 1995 03:00				
P=, Tu Jun 27 1995 03:00				
C\$, Su Jun 25 1995 00:00	C\$, Su Jun 25 1995 05:00	4	0.00	0.00
	C\$, Mo Jun 26 1995 05:00	1	0.00	0.00
C\$, Mo Jun 26 1995 17:30				
C\$, Tu Jun 27 1995 17:30				
K\$, Su Jun 25 1995 00:00	K\$, Su Jun 25 1995 06:00	4	0.00	0.00
	K\$, Mo Jun 26 1995 06:00	1	0.00	0.00
K\$, Mo Jun 26 1995 17:00				
K\$, Tu Jun 27 1995 17:00				

zero for CR is reduced from 5 to 4 and a departure is included at CR on Tuesday at 6:00 pm to construct scenario 7. This results in an infeasible

solution since the demands at CR occur before the last chassis supply at CR on Tuesday at 6:00 pm. Since there is not enough time to transport a chassis to CR for the final demand at CR, there is no feasible solution and the displayed infeasibility message is the same as that discussed for scenario 4.

Scenario 8 is the situation when total demand exceeds total supply for the chassis reallocation scenario and a feasible solution is not possible. This scenario is detected before any optimal solution is attempted and the following message is displayed to the user:

```
Demand Exceeds Supply:
Problem has NO SOLUTION
Press Any Key,,,
```

6.2.2 Verification Summary

Results from the scenarios of the previous section demonstrate the correct performance of CHREMAN in a variety of supply and demand situations. Although the set of scenarios are not comprehensive with respect to size and complexity, it is reasonable to proceed with further evaluation using more challenging problem sets.

6.3 Characterization

As discussed in section 4.6, the transportation model implemented by CHREMAN requires time and space resources in order to reach optimum solutions. These resource requirements increase as problem size increases. In the CHREMAN software implementation these resources are computer memory and execution speed. In the following sections the memory requirements and execution time of CHREMAN are characterized as a function

of problem size, where problem size is expressed in the number of supplies and demands as in section 4.6. It should be noted that the focus of the following characterizations address the optimization module of the CHREMAN system. Resource requirements for other modules in the system are effected by the size of the problem, but they are far less significant in comparison with the optimization process of the system.

6.3.1 CHREMAN Memory Requirements

Computer memory in the CHREMAN optimization module consists of a portion that is allocated statically and a portion allocated dynamically.

The static portion consist of that memory allocated as a matter of course and is a constant amount for all problem sizes. The amount of memory allocated dynamically is a function of problem size. The optimization module allocates an appropriate amount of memory during its execution upon determination of the size of the problem submitted. The size of the problem is expressed by the number of supply and demand points in the given transportation model.

There are three sets of dynamic memory allocations associated with each optimization which will be referenced here as allocations A, B, and C. Allocation A is assigned the original model specification in character format. It contains character labels identifying each supply and demand point as well as the original supply, demand, and unit cost amounts. Each unit of allocation A is 8 bytes in length. Allocation B is assigned the current solution basis along with supply and demand amounts during optimization. Allocation B is in integer numeric format, with each unit equal to 4 bytes in length. Allocation C is in floating point numeric format and requires 4 bytes for each unit. All vectors and matrices

required by the simplex operations incorporated in the solution algorithm are maintained in allocation C.

The number of units required for each allocation as a function of problem size is expressed as follows:

Given: s = number of supply points in problem
 d = number of demand points in problem

The number of units for allocations A, B, and C (U_A, U_B, U_C) are defined by:

$$U_A = sd + 3s + 2d + 9$$

$$U_B = 5s + 5d + 12$$

Keep in mind that the number of allocation units defined in the equations above must be multiplied by the number of bytes in the respective allocation units (8,4, and 4) to get the total number of bytes required for each allocation.

Table 6.14 gives examples of required dynamic memory allocations for specific problem sizes originating from the intermodal system of section 6.1. The problems shown in Table 6.14 represent chassis reallocation for periods of 6, 9, and 18 days. Problem size is shown in terms of the number of supplies and demands and the memory allocations are expressed in terms of both allocation units and kilobytes (bytes*1024).

6.3.2 CHREMAN Execution Speed

The time requirements for implementation of chassis reallocation scenarios in the CHREMAN software system are driven by the optimization portion of the system as is the case with memory requirements. Expectations of execution times are best represented by the information in

Table 6.15 which shows representative run times taken for the optimization portion of CHREMAN for the same reallocation problems presented in Table 6.14. Five samples of optimization time requirements for personal computers with 3 distinct CPUs and clock speeds (Intel DX2 50Mhz, Intel DX2 66Mhz, Intel Pentium 90Mhz) are shown for each of the problem sizes. The number of iterations required to reach the optimum solution for each

TABLE 6.14 Optimization Memory Allocations for Specific Problems

Days	Size (sXd)	U _A	8U _A (Kb)	U _B	4U _A (Kb)	U _C	4U _C (Kb)	Total Kb
6	64 X 57	3963	30.96	617	2.41	22918	89.52	122.89
9	94 X 83	8259	64.52	897	3.50	48366	188.93	256.95
18	176 X 169	30619	239.21	1737	6.78	181286	708.14	954.13

sample is also shown in Table 6.15 on the following page.

6.3.3 Characterization Summary

The memory and execution speed associated with the optimization portion of CHREMAN has been clearly defined in the preceding sections. The largest problem size covered a period of 18 days in an intermodal system with daily arrivals and departures at 8 ramps. This problem required less than 1 megabyte of dynamic memory allocation and took roughly 14 minutes to optimize with the 90Mhz computer. Considering that many computer systems far exceed the resources of personal computers, it seems that the memory and execution time requirements of CHREMAN are not excessive and should not restrict its integration into operating

environments.

TABLE 6.15 Sample Optimization Times

<u>Problem Size</u>	<u>Computer Clock Speed</u>	Sample 1 MM:SS (# iter)	Sample 2 MM:SS (# iter)	Sample 3 MM:SS (# iter)	Sample 4 MM:SS (# iter)	Sample 5 MM:SS (# iter)
64X57	50 Mhz	1:12 (67)	1:28 (94)	1:21 (80)	1:34 (104)	1:07 (56)
64X57	66 Mhz	0:59 (79)	0:48 (52)	1:03 (89)	0:55 (66)	1:15 (115)
64X57	90 Mhz	0:21 (71)	0:27 (106)	0:25 (98)	0:24 (91)	0:24 (89)
94X83	50 Mhz	5:01 (156)	4:44 (143)	5:22 (175)	5:06 (160)	5:14 (169)
94X83	66 Mhz	4:18 (193)	3:40 (153)	3:37 (149)	4:39 (216)	4:28 (202)
94X83	90 Mhz	1:39 (206)	1:23 (158)	1:17 (139)	1:40 (202)	1:25 (164)
176X169	50 Mhz	48:09 (442)	48:41 (450)	48:21 (445)	53:49 (516)	47:46 (435)
176X169	66 Mhz	37:59 (478)	35:24 (435)	36:05 (445)	38:36 (490)	33:17 (396)
176X169	90 Mhz	12:39 (397)	13:17 (422)	16:08 (547)	13:57 (450)	14:46 (490)

CHAPTER 7

RESEARCH APPLICATIONS

7.0 Introduction

Following successful design, development, and evaluation, it is beneficial to demonstrate the usefulness of the CHREMAN software system as a tool for research and analysis. In the studies that follow CHREMAN is used to generate results in designed scenarios that are submitted for subsequent analysis. The results collected for experiments discussed in this chapter are generated from the intermodal system model presented in section 6.1. An experiment concerning the length of the planning period used for chassis reallocation is conducted in the framework of the described intermodal system and discussed in section 7.1. This is followed by an experiment involving the use of CHREMAN in an environment with predicted supply and demand in section 7.2.

7.1 Planning Period Experiment

An issue that can be investigated using the CHREMAN software system concerns the length of the planning horizon used in model solutions. As discussed in Chapter 4 the model implemented by CHREMAN gives minimum cost solutions for given planning horizons. In an operational environment one concern is the effect of the length of the planning horizon on long term costs. It seems intuitive that as the length of the planning horizon increases, reallocations costs are reduced in the long run as reallocation needs are anticipated earlier. The investigation of this hypothesis was implemented in a designed experiment using results generated by CHREMAN operating within the intermodal system described in section 6.1.

7.1.1 Experimental Design

This experiment investigates the following hypothesis concerning the implementation of CHREMAN in an operational environment:

For a given planning period, the minimum cost solution for the problem defined for the entire period is less than the sum of minimum cost solutions for subproblems of equal time periods that span the same planning period.

For this experiment, solutions are generated by CHREMAN in the context of the intermodal system of section 6.1 for a planning horizon of 18 days. Three methods are used for determining total chassis reallocation cost for each 18 day period. The first method is simply the minimum cost solution generated by CHREMAN for the entire period. Method two sums the cost of two subproblems of 9 days each that cover the period of interest. The last method sums the cost of three subproblems of 6 days each that cover the same 18 day time frame of methods one and two.

The use of a six day minimum solution period is a function of the intermodal system used in the study. In this intermodal system the maximum time required to transport a chassis between two ramps in the system is just less than six days. Considering planning periods of less than six days restricts the chassis reallocation options considered in reaching solutions. This restriction of reallocation options can generate imbalances in repeated solutions that may eventually render an infeasible solution. Thus a rule of practicality for CHREMAN operation is that the planning horizon should cover an amount of time that allows chassis in the system to be transported between all ramps.

The beginning of the 18 day period in this study was chosen arbitrarily to begin at 12:00 a.m. on a Sunday and conclude at 11:59 p.m. on a Wednesday, 18 days later. For example if Sunday is August 22 the

solution periods for the problem and resulting subproblems is shown below in Table 7.1

Table 7.1

<u>Method 1(18 days)</u>	<u>Method 2(9 days)</u>	<u>Method 3(6 days)</u>
Begin: Sun Aug 22 00:00	Sun Aug 22 00:00	Sun Aug 22 00:00
End:	Mon Aug 30 23:59	Fri Aug 27 23:59
Begin:		Sat Aug 28 00:00
End:		Thu Sep 02 23:59
Begin:	Tue Aug 31 00:00	Fri Sep 03 00:00
End: Wed Sep 8 23:59	Wed Sep 08 23:59	Wed Sep 08 23:59

Cost results used in subsequent analysis were generated from repeated runs of the same 18 day period. A different set of container loadings was generated randomly for each run from the departure distributions of Table 6.7. Sampling from the departure distributions was implemented in software developed in the C programming language. Other assumptions used in the generation of cost values are as follows:

1. A sufficient supply of chassis are available in the system to meet all demands.
2. Supplies and demands are known for the entire 18 day period.
3. Chassis movements outlined in subproblem solutions are implemented in the period of time covered by the subproblem.

Assumption 1 above requires that a certain number of chassis be available at each ramp at the start of the 18 day planning period. These counts were determined by examining weekly patterns of estimated chassis supply and demand at each ramp from the given data. Assuming that there are zero chassis at each ramp at the beginning of the week, a pattern of chassis surplus and deficit can be determined at supply and demand points during the week. The number of chassis assigned to each ramp at the beginning of the 18 day period of this study is equal to the largest average weekly

deficit found for each ramp in the manner discussed above. Table 7.2 shows the assumed counts of chassis available at time zero for each ramp in the given intermodal system.

TABLE 7.2
Chassis Available, Time Zero

Ramp	Chassis Available, Time Zero
IR	37
CR	48
C=	40
R=	15
S=	28
P=	16
C\$	15
K\$	18

7.1.2 Experimental Results

A graphical representation of the distribution of the total cost values for the three methods is depicted in Figure 7.1. The total cost values generated by each of the three methods for the 25 runs of 18 days is shown in Table 7.3.

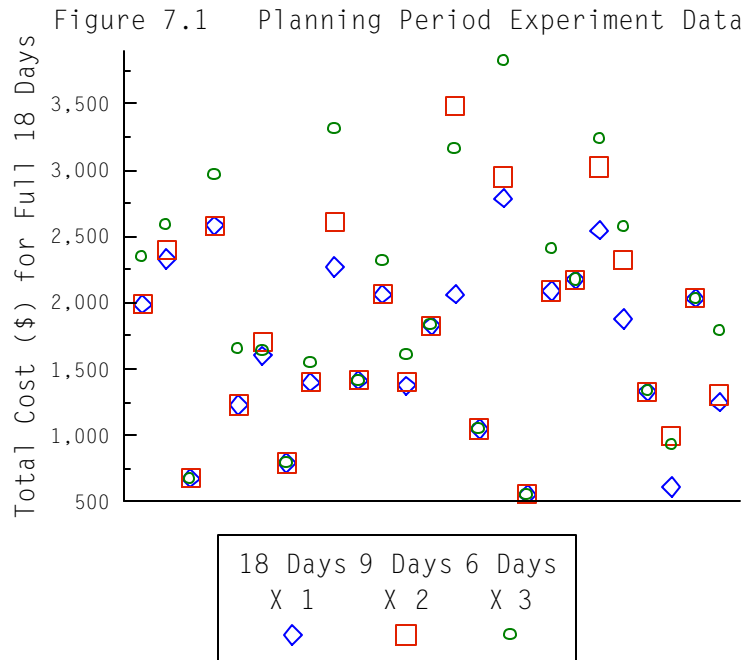


TABLE 7.3 Results of Independent Runs (Cost in \$)

Method 1 <u>Full 18 Days</u>	Method 2 <u>9 Days X 2</u>	Method 3 <u>6 Days X 3</u>
1990.00	1990.00	2340.00
2330.00	2400.00	2592.50
672.50	672.50	672.50
2582.50	2582.50	2967.50
1230.00	1230.00	1650.00
1602.50	1700.00	1630.00
792.50	792.50	792.50
1400.00	1400.00	1540.00
2270.00	2610.00	3310.00
1412.50	1412.50	1412.50
2065.00	2065.00	2310.00
1375.00	1402.50	1610.00
1827.50	1827.50	1827.50
2062.50	3482.50	3165.00
1045.00	1045.00	1045.00
2787.50	2950.00	3830.00

552.50	552.50	552.50
2087.50	2087.50	2402.50
2172.50	2172.50	2172.50
2547.50	3022.50	3230.00
1877.50	2322.50	2577.50
1330.00	1330.00	1330.00
610.00	995.00	925.00
2032.50	2032.50	2032.50
1247.50	1302.50	1785.00

7.1.3 Further Analysis

A procedure that may be used to test for significant cost differences between the three methods is a standard analysis of variance. Since there are cost values for each of the three methods for all 25 runs, the designed is balanced and is suitable for the ANOVA procedure as implemented in the SAS statistical software package. The SAS source code used in implementing this analysis of variance is given below.

```

DATA COSTDAT;
  INFILE 'PLANPER.DAT';
  INPUT RUN METHOD COST;

PROC ANOVA;
  CLASS METHOD RUN;
  MODEL COST = RUN METHOD;
  MEANS METHOD / DUNCAN LSD SCHEFFE TUKEY REGWF SMM SNK;

RUN;

```

Notice from the MODEL statement in the ANOVA procedure that both method and run number are included as factors possibly effecting cost. In this case the run number is considered a blocking factor in order to control for variability in cost between runs. The MEANS statement is included to investigate separation of mean values between the three methods.

A partial listing of the output resulting from the SAS procedure outlined above is given in Table 7.4. A complete listing of SAS output for the procedure is included in Appendix B of this document. Noteworthy information in Table 7.4 includes the significant effect of method on total cost and the separation of means of all three methods significant at an alpha level of 0.05 according to T tests. Although only the T test of mean separation is shown in Table 7.4, several mean separation tests were included in the ANOVA procedure. All of these indicate a significant separation of method 3 (6 day intervals) from the others at an alpha

TABLE 7.4 ANOVA Model of Planning Period Cost Methods

Analysis of Variance Procedure

Dependent Variable: COST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	41915782	1612145	33.24	0.0001
Error	48	2327985	48500		
Corrected Total	74	44243767			

R-Square	C.V.	Root MSE	COST Mean
0.947383	12.05747	220.23	1826.5

Source	DF	Anova SS	Mean Square	F Value	Pr > F
RUN	24	40694061	1695586	34.96	0.0001
METHOD	2	1221722	610861	12.60	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: COST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 48 MSE= 48499.69
Critical Value of T= 2.01
Least Significant Difference= 125.24

Means with the same letter are not significantly different.

T Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

level of 0.05. Three of the seven included mean separation procedures (TUKEY, SMM, SCHEFFE) indicate no significant separation between method 1 (18 day interval) and method 2 (9 day interval) at alpha level 0,05. All mean separation tests indicate significant differences between all three methods when the alpha level is set to 0.10.

7.1.4 Experimental Conclusions

Examination of the generated data and resulting analysis presented in the previous section suggest that the length of the planning period has an effect on total cost in the implementation of the CHREMAN software system in an operational environment. The conclusion is that longer planning horizons are desirable when supplies and demands are known for an approaching planning period. The likely explanation is that there are simply more options for chassis movements when considered in larger time

frames. As a planning period is shortened, options for meeting chassis demand are reduced and costs are increased until feasible solutions are eliminated for very short time periods.

7.2 Predicted Loading Experiment

The transportation model implemented in the CHREMAN software system requires input of container loadings on individual trains during the planning horizon. These loadings translate into elements of chassis supply and demand as discussed in section 4.4. In practice these numbers may not be known well in advance and will need to be estimated to some extent. In an operational environment the degree of certainty to which supply and demand is known increases as the start of a planning period approaches. This study involves the use of CHREMAN in investigating reallocation solutions in an environment of improving supply and demand predictions,

7.2.1 Experimental Design

This experiment investigates the effect of errors in container loading predictions on chassis reallocation costs in an operating environment. It is based on the assumption that certain percentages of container loading values are known at certain points in time previous to the start of the planning horizon. This leaves a portion of unknown container loadings that must be estimated at those times.

For this study, the operational intermodal system is assumed to be that described in section 6.1 and used for the experiment of section 7.1.

The planning horizon is the 9 day period used in section 7.1. It is assumed that at given points in time prior to the start of the planning horizon the portion of container loadings that have been determined are

25% and 50% respectively. The corresponding points in time can be considered 14 and 7 days. In other words, 14 days prior to the start of the planning horizon 25% of the container loads for each train are known and 75% must be estimated. Seven days prior to the start of the planning horizon 50% of the loads have been determined and 50% are estimated. In this application the known and predicted percentages are distributed evenly across all supply and demand points in the planning period. This means that the 25%/75% and 50%/50% rules are applied to each individual arrival and departure scheduled during the given period. The prediction rule for the estimated loading portions is simply the loading value for that supply or demand from the previous planning period. The known loading portions are calculated from assumed actual loadings from the planning period. The procedure to obtain the container loading was implemented in software according to the steps outlined as follows:

1. Generate assumed actual container loadings for the planning period.
2. Generate assumed historical container loadings for the previous planning period.
3. Calculate 1st loading estimates as 25% actual and 75% historical.
4. Calculate 2nd loading estimates as 50% actual and 50% historical.

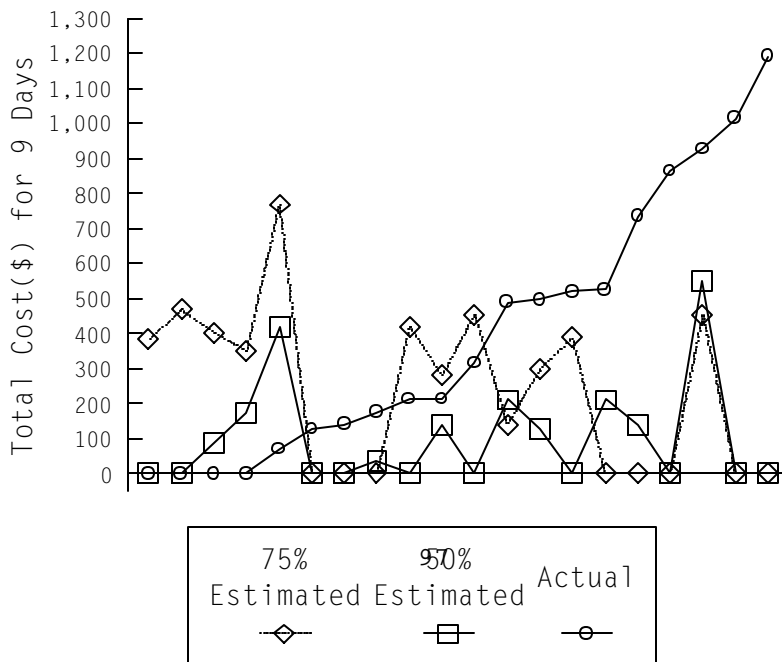
CHREMAN solutions may be obtained for the estimated and actual loadings for comparison purposes. Thus for each run a CHREMAN solution is required for the assumed actual, 25%/75% known/estimated, and 50%/50% known/estimated loadings.

7.2.2 Experimental Results

Minimum cost results from 20 runs of combined predicted and actual

loadings is shown in Figure 7.2. The results from the runs illustrated in the figure have been arranged from left to right in ascending order of actual cost. Results from runs containing estimated loadings are aligned vertically with the results from the associated actual cost runs. Notice that costs from the 75% estimated loadings appear somewhat more variable in comparison to costs from the 50% estimated loadings. Also more of the costs from the 50% estimated loadings are closer to the actual cost than costs from the 75% estimated loadings. Table 7.5 contains the actual cost results from the 20 runs in addition to values that represent measures of error in the predicted loadings. Columns 1,2, and 5 show the minimum cost solutions for assumed actual, 50% estimated, and 75% estimated container loadings respectively. Again the information associated with individual runs in each row has been sorted by ascending order of the actual minimum cost solution. Columns 3 and 6 in Table 7.5 shows the percent error in

Figure 7.2 Container Loading Results



total loadings between the actual and the given estimated loadings. It is simply the total estimated containers over the total actual containers minus one. A positive error percentage indicates an overestimate in total loadings and a negative value indicates an underestimate. Columns 4 and 7 in Table 7.5 show the average deviation of individual predicted supplies and demands as a percentage of the actual loadings. This is intended to provide an indication of the difference between individual predicted and actual loadings. Comparisons between values in columns 3 and 6 along with comparisons of columns 4 and 7 demonstrate the improvement from estimating 75% of the loadings to estimating 50%.

TABLE 7.5 Run Results - Container Loading Experiment

<u>Actual</u> Minimum Cost Solution	<u>50% Est.</u> Minimum Cost Solution	<u>50% Est.</u> Total Loading Error(%)	<u>50% Est.</u> Avg % Dev from Actual	<u>75% Est.</u> Minimum Cost Solution	<u>75% Est.</u> Total Loading Error(%)	<u>75% Est.</u> Avg % Dev from Actual
0.00	0.00	3.22	55.39	382.50	5.04	78.68
0.00	0.00	5.38	40.8	467.50	7.17	54.94
0.00	85.00	0.00	39.81	402.50	0.68	61.26
0.00	175.00	2.78	56.12	350.00	4.69	83.59
70.00	420.00	2.65	39.77	770.00	4.46	57.50
127.50	0.00	4.22	42.97	0.00	6.48	59.35
140.00	0.00	2.16	44.69	0.00	2.78	69.75
175.00	35.00	-2.71	40.39	0.00	-3.92	58.39
212.50	0.00	1.35	32.41	420.00	2.29	45.46

212.50	140.00	-3.97	39.77	280.00	-4.54	56.59
315.00	0.00	0.56	39.95	455.00	1.70	51.35
490.00	210.00	-3.89	40.26	140.00	-4.58	60.27
497.50	127.50	-2.00	45.92	297.50	-3.07	66.86
520.00	0.00	0.85	43.35	387.50	0.71	61.15
525.00	210.00	-6.04	37.76	0.00	-10.44	50.67
735.00	140.00	-3.46	40.51	0.00	-2.49	65.99
865.00	0.00	-2.07	58.92	0.00	-2.36	84.37
927.50	547.50	-4.93	42.56	455.00	-8.17	64.22
1015.00	0.00	-3.83	33.03	0.00	-4.42	51.97
1192.50	0.00	-2.31	42.26	0.00	-3.39	65.67

7.2.3 Experimental Conclusions

Examination of the minimum costs solutions in Table 7.5 reveals results that are reasonably consistent with expectations in most cases. Either there is a trend of increasing cost with improved prediction (rows 8,12,15,16,18) or decreasing cost with improved predictions (rows 1-5). Runs with zero cost associated with predicted loadings are not considered inconsistent though some differ more with the actual solutions than others (rows 6,7,17,19,20). Roughly 25% of the runs show a cost decrease between the 75% and 50% estimations followed by an increase in the actual solution that is not consistent with an improved estimate.

Examination of the error values reveals no detectable pattern between the magnitude of the prediction errors and the differences in minimum cost solutions with the estimated and actual loadings. It is interesting to note that the underestimated loadings tend to be grouped with the higher cost actual solutions at the bottom of Table 7.5. Perhaps this is explained by the fact that predictions are based on the loadings

of the previous planning period and that demand has increased over the previous period. This could result in the underestimated loadings and an increase in cost associated with meeting the increased demand.

Overall these results are not disappointing in the context of predictions based on the previous planning period only. The incorporation of CHREMAN into an environment of partially estimated container loadings will provide useful information when combined with a well developed estimation mechanism.

CHAPTER 8

CONCLUSIONS AND FUTURE RESEARCH

8.0 Introduction

The focus of this dissertation has been the development of a model to assist in chassis reallocation decisions associated with container based traffic in intermodal transportation systems. The model has been included in a functioning software system that has been evaluated as a tool for industrial and research purposes. The remainder of this work consists of conclusions about the model and the associated CHREMAN software system in section 8.1 followed by a discussion of possible future considerations in section 8.2.

8.1 Conclusions

The time based transportation model for optimization of chassis reallocation presented in Chapter 4 of this document addresses the problem of redistributing chassis associated with container service in the intermodal transportation industry. The evolution of this model into the CHREMAN software system is discussed in Chapter 5 and the software is verified to be functioning as intended in Chapter 6. The characterization of software execution time and memory requirements is also in Chapter 6 and is followed by the demonstration of CHREMAN as a research tool in Chapter 7. Results obtained in Chapters 6 and 7 demonstrate CHREMAN operation in a realistic intermodal system. These research results show potential for the application of CHREMAN in both industrial and research environments.

In industrial environments, the analysis here suggest that a minimum

period of time for optimizing chassis reallocations using CHREMAN is the maximum time required for transporting a chassis between two ramps in the system. When supplies and demands are known, minimum cost solutions for longer planning periods are preferred over a series of shorter periods. In practice these supplies and demands not are all known well in advance and will have to be forecast. CHREMAN can be used successfully in an environment with forecast supply and demand in combination with a good forecast mechanism.

The use of CHREMAN in research applications has been demonstrated in this work. As a software system, CHREMAN has the ability to generate results quickly in designed scenarios. It also has the flexibility needed to incorporate additional features that might be required for related studies.

8.2 Future Research

Foremost among future considerations is the inclusion of CHREMAN in an industrial operating environment. This can be done by linking CHREMAN into a system that provides chassis location information as well as actual and/or predicted supply and demand. This could also be done more cautiously by incorporating additional analysis of supply and demand structures of specific intermodal systems and studying additional methods of implementation.

Although speed and memory resources of personal computers are now impressive and continue to improve rapidly, it is possible to port CHREMAN to a larger computer system if more resources are needed. This can be expected to be a relatively straightforward process.

Other ideas involve the evolution or inclusion of CHREMAN in

increasingly complex systems. As it stands, CHREMAN is a decision support system that optimizes chassis movements based on cost and time. More complex decisions incorporating additional equipment or fleet management issues may be addressed by developing CHREMAN into an expert system with additional decision rules encompassing a more general problem. CHREMAN could also be included as an optimization portion of a simulator for investigating scenarios in fleet management.

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APPENDIX A

CHREMAN User's Guide

CHREMAN
User's Guide
Version 1.0, 1995

CHAPTER 1 - Installation

This chapter describes the computer system requirements to install and run the CHREMAN software system and gives installation instructions.

System Requirements

Minimum hardware requirements are: IBM compatible personal computer with Intel 486 or Pentium processor with clock speed 50 MHZ or higher; DOS 5.0 or higher; 640K RAM; EGA or VGA video graphics capabilities; and a hard drive with 1MB free disk space.

Installation Procedure

Installation of the CHREMAN software system may be accomplished by following the steps below.

1. Make a directory on your hard drive to store the CHREMAN executable files. For example, if you are installing to the C: disk drive the DOS command might be as follows:

```
C:\> md \chreman
```

2. Copy all the files on the distribution diskette to the directory you just created. For example, if the distribution diskette is in drive A: the DOS command might be:

```
C:\> copy a:\*.* c:\chreman
```

Starting and Stopping CHREMAN

To start CHREMAN change to the directory where CHREMAN is installed and type CHREMAN. For example

```
C:> cd \chreman  
C:\CHREMAN> chreman
```

System operation begins at the main CHREMAN System Menu. To stop CHREMAN execution press F3 from the main CHREMAN System Menu.

CHAPTER 2 - CHREMAN System Overview

Cost efficiencies associated with double stacking truck containers on flatbed railcars have motivated carriers to increase their involvement in intermodal freight transportation. However, container-on-flatcar (COFC) service in rail-truck environments requires maintenance of a separate chassis fleet for highway transport. Containers arriving at intermodal terminals (ramps) must be loaded on available highway chassis in order to be moved by truck. Conversely, containers must be detached from truck and chassis to be loaded on departing trains. The nature of normal business activity does not guarantee that a sufficient pool of chassis will remain at all ramps due to variation in container loadings. Ramps that have more arrivals than departures over time can deplete a supply of chassis unless some action is taken to redistribute chassis on a timely basis.

CHREMAN stands for CHassis REallocation MANager. It is a decision support system developed to assist with chassis distribution management on a regular basis. CHREMAN is based on an optimization model that requires information regarding the desired planning period, intermodal train schedules, chassis and container locations, and chassis transport costs. This information is used to optimize the given problem with a minimum cost objective. Model output is a suggested chassis redistribution for the given time period.

CHREMAN provides support in two functional areas. These areas are intermodal train schedule maintenance and chassis reallocation management. These two functions are related since current intermodal train schedules are required as input during chassis reallocation scenarios.

Intermodal train schedules are maintained through the use of the Schedule Manager portion of the system. These functions are enabled by electing to update train schedules from the main CHREMAN System Menu. The Schedule Manager permits the user to add, delete, and modify terminal schedules as well as providing display and print functions.

Chassis reallocation management is implemented by electing to execute a reallocation scenario from the CHREMAN System Menu. During this process, information is elicited from the user concerning the desired planning period, container loads on trains during the period, and chassis transportation cost. This information is then used in the optimization process that determines a minimum cost chassis reallocation for the desired period of time.

CHAPTER 3 - The User Interface

Operations of the CHREMAN system are implemented by user interaction with two types of interfaces. The first interface is a menu interface in which the user selects an option by highlighting the desired option using the up arrow (8) and down arrow (9) keys and then pressing the Enter (5) key. The second type of interface is a forms input interface that allows user input of required data. During forms input, the user types in the needed information using the alphanumeric keys of the keyboard and is allowed to navigate through the form using the arrow keys (89), the Enter (5) key, and the Page Up and Page Down keys. The paging keys move the user through the form one screen at a time while the other keys navigate through individual fields. In order to save the information entered on a particular form, the user must press the F10 key. After pressing the F10 key the user is prompted to verify that the desire is to save and exit. Pressing the "Y" key (or the "y" key) results in the storage of the information on the form for subsequent use. Pressing any other key at this point returns the user to forms editing.

Throughout the CHREMAN system, the Exit (or Abort) key is the F3 key. During forms input, pressing the F3 key results in the user being prompted as to whether the desire is to abort the edit without saving any information entered. Pressing the "Y" key (or the "y" key) results in a return to the previous system menu without any data being saved. Pressing any other key at this point returns the user to forms editing. When the user is presented with a menu interface, pressing the F3 key exits to the previous menu. If the menu displayed is the top level CHREMAN Systems Menu, then pressing the F3 key exits the CHREMAN system.

At all times during CHREMAN operation, the action keys available to the user are displayed on the screen. At a menu interface, pressing a key other than the valid ones displayed results in no action being taken. During forms input, only alphanumeric keys that are valid with respect to the specific field being edited are permitted in addition to the displayed action keys.

CHAPTER 4 - System Level Operations

The main CHREMAN Systems Menu is illustrated in Figure 4.1. It is a menu interface that offers three selections to the user.

The first selection permits the user to display, print, or update intermodal train schedules using the Schedule Manager. The use of the Schedule Manager is discussed in Chapter 5 of this document.

The second option available from the CHREMAN Systems Menu allows the user to update estimates of the time and cost requirements associated with transporting chassis between intermodal terminals in the system. This function is addressed in Chapter 6 of this document.

The third option of the CHREMAN Systems Menu initiates a chassis reallocation scenario for an approaching time period. Forms input of the desired planning period, container loadings, and chassis transportation costs are required prior to execution of the optimization process associated with chassis redistribution for the given period. Chassis reallocation scenarios are presented in Chapter 7 of this user's guide.

Figure 4.1 CHREMAN Systems Menu

```

                                CHASSIS REALLOCATION MANAGER

                                +-----SELECT FUNCTION-----+
                                |Update Train Schedules          |
                                |Update Time/Cost Estimates       |
                                |Execute Reallocation Scenario   |
                                +-----+
                                +-----+
                                |  Use 8 or 9 then 5            |
                                +-----+

                                -----Message Area-----

                                <F3>Exit

```


Figure 5.2 Example Intermodal Terminal Display

```
||||| Terminal Display |||||
Terminal Abbreviation      Terminal Name
IR                          Illinois Ramp
CR                          California Ramp
C=                          Chicago Ramp
R=                          Denver Ramp
S=                          Seattle Ramp
P=                          Portland Ramp
C$                          Chicago Conrail Ramp
K$                          Kearny Conrail Ramp
||||| PAGE UP/DOWN to Scroll; F3,Esc,Enter to Exit |||||
```

Figure 5.3 Terminal Abbreviation Prompt

```

                                SCHEDULE MANAGER
                                +-----SELECT FUNCTION-----+
                                |Display Terminals                |
                                |Add a Terminal                   |
                                |Delete a Terminal                |
                                |Display a Terminal Schedule      |
                                |Modify a Terminal Schedule       |
                                |Print a Terminal Schedule        |
                                +-----+
                                | Use 8 or 9 then 5              |
                                +-----+
                                +-----+
                                |Enter Terminal Abbreviation:    |
                                +-----+
                                -----Message Area-----
                                <F3>Abort      <F10>Save Changes and Exit
```

terminal. Examples of arrival and departure input screens are shown in Figures 5.5 and 5.6 respectively. After all arrival and departure information is entered for the new terminal, it is added to the master train schedule file. When the CHREMAN system is run for the first time after CHREMAN installation, no master schedule file exists. It is created when the first intermodal terminal is added using the Schedule Manager.

Figure 5.4 Terminal Information Input Form

```
|||| Container Schedule Update |||  
  
Terminal Abbreviation: IR  
  
Terminal Name: Illinois Ramp  
  
Number of Weekly Arrivals: 7  
  
Number of Weekly Departures: 7  
  
|| 89, ENTER to change fields; F10 to save; F3 to Abort |||
```

Figure 5.5 Terminal Arrival Input Form

```
|||| Container Schedule Update |||  
  
Terminal: IR, Illinois Ramp  
  
ARRIVAL 1  
  
Arrival Day: 1  
  
Arrival Time: 3:00  
  
|| 89, ENTER to change fields; F10 to save; F3 to Abort |||
```

Figure 5.6 Terminal Departure Input Form

```
||||| Container Schedule Update |||||
Terminal: IR, Illinois Ramp
DEPARTURE 1
Departure Day: 1
Departure Time: 17:30
|| 89, ENTER to change fields; F10 to save; F3 to Abort |||
```

The third option in schedule management allows the user to delete an intermodal terminal. When this option is selected the user is prompted to enter the terminal abbreviation as shown in Figure 5.3. If the terminal exists, the information for that terminal is deleted from the master schedule file after the request is verified by the user.

The fourth option in the Schedule Manager menu permits the display of an intermodal train schedule associated with a given intermodal terminal. After obtaining the terminal abbreviation from the user, the schedule is displayed for perusal. An example terminal schedule display is shown in Figure 5.7.

Figure 5.7 Example Terminal Schedule Display

```
||||| Schedule Display |||||
Terminal IR, Illinois Ramp
Arrival Day/Time      Departure Day/Time
SU 3:00                SU 17:30
SU 20:00               MO 17:30
MO 8:00                TU 17:30
WE 3:00                WE 17:30
TH 3:00                TH 17:30
FR 3:00                FR 17:30
SA 3:00                SA 17:30
||||| PAGE UP/DOWN to Scroll; F3,Esc,Enter to Exit |||||
```

The fifth option in the Schedule Manager allows the user to modify the intermodal train schedule for an existing intermodal terminal. The procedure is much the same as that for adding new terminals as shown in Figures 5.3 through 5.6. A feature of this part of the system is that an attempt is made minimize user input by not requiring a complete re-entry of schedule information during this modification. This is done by retaining the original schedule information and adjusting it according to the new number of arrivals and departures. If the number of arrivals or departures decrease to n for instance, the first n arrivals or departures of the original data are displayed for editing. If the number of arrivals or departures increase to n from m the first m arrivals or departures are displayed for editing followed by $n-m$ screens of empty departure or arrival data to be input.

The last schedule management option permits a terminal schedule as shown in Figure 5.7 to be sent to a printer.

CHAPTER 6 - Updating Time/Cost Estimates

Part of the information required to implement chassis reallocation scenarios are user estimates of time and costs requirements for transporting chassis between terminals in the system. These estimates are required for each terminal pair in the system and consist of 1) the estimated time required to transport a chassis from terminal 1 to terminal 2 of the terminal pair; and 2) the unit cost of transporting a chassis from terminal 1 to terminal 2.

Time and cost estimates may occur during CHREMAN operation in 2 different situations. One situation occurs when the user selects option 2 from the main CHREMAN System Menu. In this manner the time and cost estimates for the current intermodal system may be updated at the discretion of the user. The second method of time and cost estimation occurs when certain changes are made to the master train schedule file. More specifically, the addition or deletion of intermodal terminals from the master schedule file means that the terminal pairings have changed and time and cost estimates must be updated. In this case the time/cost estimation process is automatically executed when the identified changes are saved to the master schedule file upon termination of the Schedule Manager. Fortunately a complete re-entry of time/cost estimates is not required since the previous values are retained for those terminal pair matches still intact from the previous schedule. New estimates will have to be made for newly added terminals. When time/cost estimation is invoked automatically, the user may not exit without saving the new time/cost estimates since they must match up with the master schedule file. An example of the time/cost screen entry form is shown in Figure 6.1.

Figure 6.1 Time/Cost Estimation Entry Form

```

|||||Relocation Times and Costs|||||
|
|      From              To              Allowed Time    Cost/Unit
|
| Illinois Ramp         Illinois Ramp         0      hrs      0
| Illinois Ramp         California Ramp       62.5   hrs      42.5
| Illinois Ramp         Chicago Ramp          2      hrs      35
| Illinois Ramp         Denver Ramp          32.5167 hrs    77.5
| Illinois Ramp         Seattle Ramp         67.4833 hrs    77.5
| Illinois Ramp         Portland Ramp        59.5    hrs    77.5
| Illinois Ramp         Chicago Conrail Ramp  2      hrs      35
| Illinois Ramp         Kearny Conrail Ramp  38.5   hrs    77.5
| California Ramp      Illinois Ramp         64     hrs    42.5
| California Ramp      California Ramp       0      hrs      0
|
|      More fields follow... Press PageUp/PageDown to Scroll
|
| ||| UP/DOWN ARROW, ENTER to change fields, F10 to save, F3 to abort |||

```

CHAPTER 7 - Reallocation Scenarios

CHREMAN chassis reallocation scenarios may be investigated by selecting option 3 from the CHREMAN System Menu. When this occurs the input form illustrated in Figure 7.1 is presented for identification of the desired planning horizon.

Figure 7.1 Planning Horizon Input Form

```
||||| Planning Horizon |||||
|
|          START TIME          STOP TIME
|
|      Day: SU                Day: MO
|
|      Date: 8/22/93          Date: 8/30/93
|
|      Time: 0:00            Time: 23:59
|
|
|      Exit and Save Screen Information?<y,n>?
|
|      UP/DOWN ARROW, ENTER to change fields, F10 to save, F3 to abort|
```

Once the planning horizon is specified, the user must enter supply and demand inputs representing existing chassis supplies at terminals, plus actual or estimated counts of containers associated with each scheduled intermodal train during the planning horizon. Chassis supplies are associated with chassis available at time zero and those left by departing trains during the planning horizon. Figure 7.2 is an example of a chassis supply input form. Chassis demands are associated with containers on arriving trains during the planning period. A chassis demand input form is illustrated in Figure 7.3.

After supply and demand inputs are saved, the current chassis transport time and cost estimates are used to estimate the unit cost of transporting chassis for each supply/demand pair. If the given time does not permit a chassis transport then the match is considered infeasible. If time does allow a transport, the estimated unit cost is used as an original basis for the supply demand pair. The results of the estimation process are displayed to the user for possible editing as shown in Figure 7.4. Once the unit costs are saved, the optimization process begins.

Optimization is a two stage process that consist of determining a starting solution and then optimizing for minimum cost. Messages are displayed on the screen during each stage of optimization along with an iteration count as an indication of progress to the user. These status messages are illustrated in Figures 7.5 and 7.6 respectively.

Figure 7.2 Chassis Supply Input Form

SUPPLY INPUT						
Event	Terminal	Time			Unit Count	
AVAILABLE AT START TIME	IR	Sun Aug 22	00:00:00	1993	37	
DEPARTURE	IR	Sun Aug 22	17:30:00	1993	5	
DEPARTURE	IR	Mon Aug 23	17:30:00	1993	12	
DEPARTURE	IR	Tue Aug 24	17:30:00	1993	11	
DEPARTURE	IR	Wed Aug 25	17:30:00	1993	13	
DEPARTURE	IR	Thu Aug 26	17:30:00	1993	6	
DEPARTURE	IR	Fri Aug 27	17:30:00	1993	2	
AVAILABLE AT START TIME	CR	Sun Aug 22	00:00:00	1993	48	
DEPARTURE	CR	Sun Aug 22	18:00:00	1993	11	
DEPARTURE	CR	Mon Aug 23	18:00:00	1993	8	

More fields follow... Press PageUp/PageDown to Scroll

Page Up/Down, 89, ENTER to change fields; F10 to Save; F3 to Abort

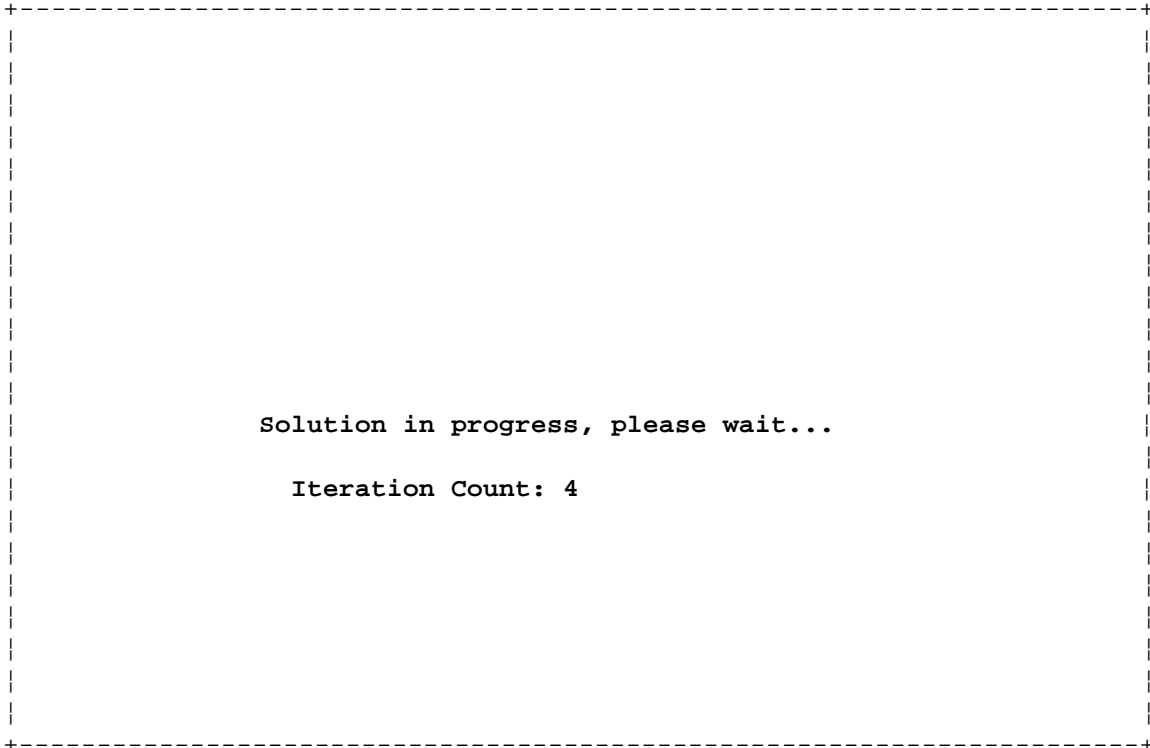
Figure 7.3 Chassis Demand Input Form

DEMAND INPUT						
Event	Terminal	Time			Unit Count	
ARRIVAL	IR	Sun Aug 22	03:00:00	1993	3	
ARRIVAL	IR	Sun Aug 22	20:00:00	1993	11	
ARRIVAL	IR	Mon Aug 23	08:00:00	1993	5	
ARRIVAL	IR	Wed Aug 25	03:00:00	1993	7	
ARRIVAL	IR	Thu Aug 26	03:00:00	1993	8	
ARRIVAL	IR	Fri Aug 27	03:00:00	1993	12	
ARRIVAL	CR	Sun Aug 22	08:00:00	1993	4	
ARRIVAL	CR	Mon Aug 23	08:00:00	1993	17	
ARRIVAL	CR	Tue Aug 24	08:00:00	1993	8	
ARRIVAL	CR	Wed Aug 25	08:00:00	1993	5	

More fields follow... Press PageUp/PageDown to Scroll

Page Up/Down, 89, ENTER to change fields; F10 to Save; F3 to Abort

Figure 7.6 Optimization Status Message



Once the optimum solution is reached, reallocation results are displayed as shown in Figure 7.7. These results suggest minimum cost chassis movements that may be implemented during the planning period. At the solution screen, users may page through the solution set, exit the system, or select the Options Menu for additional options.

The Options Menu is shown in Figure 7.8. The first option allows the user to return to view the optimum solution. The second option allows for sending the solution summary to the printer. The third option allows the user to investigate alternative optimum solutions. The fourth option of the Options Menu returns to the supply/demand input stage of chassis reallocation shown in Figure 7.2. This allows the user to repeat optimization for a similar problem. The last selection in the Options Menu returns to the planning horizon definition point of the process shown in Figure 7.1. This initiates a reallocation scenario for a different planning horizon.

Figure 7.7 Optimum Results

```

+-----+
|Chassis Allocation Problem  Size:(64 x 57)  (Final) Iteration No: 92
+-----+
|
|          *** OPTIMUM SOLUTION ***
|
|Total cost =   340.0000 (Alternate soln detected at route <62,56>)
+-----+
|
|  Supply Source                Demand At                Units Cost/Un Rte.Cost
+-----+
|C$,Mo Aug 23 1993 17:30
|C$,Tu Aug 24 1993 17:30  C$,We Aug 25 1993 05:00  5    0.00    0.00
|                          K$,Th Aug 26 1993 06:00  4   42.50   170.00
|C$,We Aug 25 1993 17:30  C$,Th Aug 26 1993 05:00  5    0.00    0.00
|                          C$,Fr Aug 27 1993 05:00  4    0.00    0.00
|                          K$,Fr Aug 27 1993 06:00  4   42.50   170.00
|C$,Th Aug 26 1993 17:30
|C$,Fr Aug 27 1993 17:30
|K$,Su Aug 22 1993 00:00  K$,Su Aug 22 1993 06:00  3    0.00    0.00
|                          K$,Mo Aug 23 1993 06:00  5    0.00    0.00
|
|          More to come... Press PgDn/PgUp to scroll
|
+-----+ <PgUp/PgDn>Scroll <F2>Options Menu <F3>Exit +-----+

```

Figure 7.8 The Options Menu

```

+-----+
|          OPTIONS          +-----+
|View solution summary    |
|Print solution summary   |
|Obtain alternative optimum|
|Edit supply/demand/cost input|
|New Planning Horizon     |
+-----+
|
|  Use 8 or 9 then 5
|
+-----+
|
|-----Message Area-----
|
|          <F3> Exit
|
+-----+

```

APPENDIX B

SAS LISTINGS FOR THE EXPERIMENT OF SECTION 7.1

B.0 SAS SOURCE CODE

This section contains listings of the SAS source code used for the planning period experiment of section 7.1

B.0.1 ALPHA LEVEL FOR MEAN SEPARATION = 0.05

```
data costdat;
  infile 'planper.dat';
  input run method cost;

proc anova;
  class method run;
  model cost = run method;
  means method / duncan lsd scheffe tukey regwf smm snk;

run;
```

B.0.2 ALPHA LEVEL FOR MEAN SEPARATION = 0.10

```
data costdat;
  infile 'planper.dat';
  input run method cost;

proc anova;
  class method run;
  model cost = run method;
  means method / duncan lsd scheffe tukey regwf smm snk alpha=.1;

run;
```

B.1 INPUT DATA FILE

The input data file used for all SAS procedures is listed below.

```
1 1 1990.0
1 2 1990.0
1 3 2340.0
2 1 2330.0
2 2 2400.0
2 3 2592.5
3 1 672.5
3 2 672.5
3 3 672.5
4 1 2582.5
4 2 2582.5
4 3 2967.5
5 1 1230.0
```

5	2	1230.0
5	3	1650.0
6	1	1602.5
6	2	1700.0
6	3	1630.5
7	1	792.5
7	2	792.5
7	3	792.5
8	1	1400.0
8	2	1400.0
8	3	1540.0
9	1	2270.0
9	2	2610.0
9	3	3310.0
10	1	1412.5
10	2	1412.5
10	3	1412.5
11	1	2065.0
11	2	2065.0
11	3	2310.0
12	1	1375.0
12	2	1402.5
12	3	1610.0
13	1	1827.5
13	2	1827.5
13	3	1827.5
14	1	2062.5
14	2	3482.5
14	3	3165.0
15	1	1045.0
15	2	1045.0
15	3	1045.0
16	1	2787.5
16	2	2950.0
16	3	3830.0
17	1	552.5
17	2	552.5
17	3	552.5
18	1	2087.5
18	2	2087.5
18	3	2402.5
19	1	2172.5
19	2	2172.5
19	3	2172.5
20	1	2547.5
20	2	3022.5
20	3	3230.0
21	1	1877.5
21	2	2322.5
21	3	2577.5
22	1	1330.0
22	2	1330.0
22	3	1330.0

```

23 1 610.0
23 2 995.0
23 3 925.0
24 1 2032.5
24 2 2032.5
24 3 2032.5
25 1 1247.5
25 2 1302.5
25 3 1785.0

```

B.2 SAS OUTPUT

This section contains listings of the SAS output obtained from the source code and input data of the previous 2 sections.

B.2.1 ALPHA LEVEL FOR MEAN SEPARATION = 0.05

```

The SAS System 67
16:53 Saturday, June 17, 1995

```

Analysis of Variance Procedure Class Level Information

Class	Levels	Values
METHOD	3	1 2 3
RUN	25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Number of observations in data set = 75

```

The SAS System 68
16:53 Saturday, June 17, 1995

```

Analysis of Variance Procedure

Dependent Variable: COST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	41915782	1612145	33.24	0.0001
Error	48	2327985	48500		
Corrected Total	74	44243767			

R-Square	C.V.	Root MSE	COST Mean

	0.947383	12.05747	220.23	1826.5	
Source	DF	Anova SS	Mean Square	F Value	Pr > F
RUN	24	40694061	1695586	34.96	0.0001
METHOD	2	1221722	610861	12.60	0.0001

The SAS System 69
16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

T tests (LSD) for variable: COST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 48 MSE= 48499.69
Critical Value of T= 2.01
Least Significant Difference= 125.24

Means with the same letter are not significantly different.

T Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

The SAS System 70
16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: COST

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 48 MSE= 48499.69
Number of Means 2 3
Critical Range 125.2 131.7

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

The SAS System 71
16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

Student-Newman-Keuls test for variable: COST

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 48 MSE= 48499.69

Number of Means 2 3
Critical Range 125.24372 150.64641

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

The SAS System 72
16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

Ryan-Einot-Gabriel-Welsch Multiple F Test for variable: COST

NOTE: This test controls the type I experimentwise error rate.

Alpha= 0.05 df= 48 MSE= 48499.69

Number of Means 2 3
Critical F 4.0426521 3.1907273

Means with the same letter are not significantly different.

REGWF Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

The SAS System 73
16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

Tukey's Studentized Range (HSD) Test for variable: COST

NOTE: This test controls the type I experimentwise error rate,
but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 48 MSE= 48499.69
Critical Value of Studentized Range= 3.420
Minimum Significant Difference= 150.65

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
B			
B	1676.10	25	1

The SAS System 74
16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

Studentized Maximum Modulus (GT2) Test for variable: COST

NOTE: This test controls the type I experimentwise error rate,
but generally has a higher type II error rate than REGWQ.

Alpha= 0.05 df= 48 MSE= 48499.69
Critical Value of Studentized Maximum Modulus= 2.471
Minimum Significant Difference= 153.89

Means with the same letter are not significantly different.

SMM Grouping	Mean	N	METHOD
--------------	------	---	--------

A	1988.12	25	3
B	1815.20	25	2
B			
B	1676.10	25	1

The SAS System 75
 16:53 Saturday, June 17, 1995

Analysis of Variance Procedure

Scheffe's test for variable: COST

NOTE: This test controls the type I experimentwise error rate but generally has a higher type II error rate than REGWF for all pairwise comparisons

Alpha= 0.05 df= 48 MSE= 48499.69
 Critical Value of F= 3.19073
 Minimum Significant Difference= 157.35

Means with the same letter are not significantly different.

Scheffe Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
B			
B	1676.10	25	1

B.2.2 ALPHA LEVEL FOR MEAN SEPARATION = 0.10

The SAS System 1
 18:53 Monday, June 19, 1995

Analysis of Variance Procedure
 Class Level Information

Class	Levels	Values
METHOD	3	1 2 3
RUN	25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Number of observations in data set = 75

Analysis of Variance Procedure

Dependent Variable: COST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	41915782	1612145	33.24	0.0001
Error	48	2327985	48500		
Corrected Total	74	44243767			

R-Square	C.V.	Root MSE	COST Mean
0.947383	12.05747	220.23	1826.5

Source	DF	Anova SS	Mean Square	F Value	Pr > F
RUN	24	40694061	1695586	34.96	0.0001
METHOD	2	1221722	610861	12.60	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: COST

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.1 df= 48 MSE= 48499.69
 Critical Value of T= 1.68
 Least Significant Difference= 104.47

Means with the same letter are not significantly different.

T Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

18:53 Monday, June 19, 1995

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: COST

NOTE: This test controls the type I comparisonwise error rate,
not the experimentwise error rate

Alpha= 0.1 df= 48 MSE= 48499.69

Number of Means	2	3
Critical Range	104.5	110.3

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

18:53 Monday, June 19, 1995

Analysis of Variance Procedure

Student-Newman-Keuls test for variable: COST

NOTE: This test controls the type I experimentwise error rate
under the complete null hypothesis but not under partial
null hypotheses.

Alpha= 0.1 df= 48 MSE= 48499.69

Number of Means	2	3
Critical Range	104.47337	130.96033

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

Analysis of Variance Procedure

Ryan-Einot-Gabriel-Welsch Multiple F Test for variable: COST

NOTE: This test controls the type I experimentwise error rate.

Alpha= 0.1 df= 48 MSE= 48499.69

Number of Means	2	3
Critical F	2.813081	2.4166601

Means with the same letter are not significantly different.

REGWF Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

Analysis of Variance Procedure

Tukey's Studentized Range (HSD) Test for variable: COST

NOTE: This test controls the type I experimentwise error rate,
but generally has a higher type II error rate than REGWQ.

Alpha= 0.1	df= 48	MSE= 48499.69
Critical Value of Studentized Range= 2.973		
Minimum Significant Difference= 130.96		

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

Analysis of Variance Procedure

Studentized Maximum Modulus (GT2) Test for variable: COST

NOTE: This test controls the type I experimentwise error rate,
but generally has a higher type II error rate than REGWQ.

Alpha= 0.1 df= 48 MSE= 48499.69
Critical Value of Studentized Maximum Modulus= 2.171
Minimum Significant Difference= 135.25

Means with the same letter are not significantly different.

SMM Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

Analysis of Variance Procedure

Scheffe's test for variable: COST

NOTE: This test controls the type I experimentwise error rate but
generally has a higher type II error rate than REGWF for
all pairwise comparisons

Alpha= 0.1 df= 48 MSE= 48499.69
Critical Value of F= 2.41666
Minimum Significant Difference= 136.94

Means with the same letter are not significantly different.

Scheffe Grouping	Mean	N	METHOD
A	1988.12	25	3
B	1815.20	25	2
C	1676.10	25	1

OPTIMIZATION OF CHASSIS REALLOCATION IN DOUBLESTACK
CONTAINER TRANSPORTATION SYSTEMS

Abstract of dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

By

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ABSTRACT

Cost efficiencies associated with double stacking truck containers on flatbed railcars have motivated carriers to increase their involvement in intermodal freight transportation. However, container-on-flatcar (COFC) service in rail-truck environments requires maintenance of a separate chassis fleet for highway transport. Containers arriving at intermodal terminals (ramps) must be loaded on available highway chassis in order to be moved by truck. Conversely, containers must be detached from truck and chassis to be loaded on departing trains. The nature of normal business activity does not guarantee that a sufficient pool of chassis will remain at all ramps due to variation in container loadings. Ramps that have more arrivals than departures over time can deplete a supply of chassis unless some action is taken to redistribute chassis on a timely basis.

This research has led to the development of a transportation model to assist in chassis reallocation decisions. Information regarding intermodal train schedules, chassis and container locations, and chassis transport costs are included as inputs to the model, which optimizes the given problem with a minimum cost objective. Model output is a suggested chassis redistribution for a given time period.

The development of a software implementation of the model for use on IBM compatible personal computers is presented with an objective of assisting with chassis reallocation on a continuing basis. The correctness of the software is verified before characterizing the associated computing resource requirements. The utility of the software is demonstrated in designed experiments and the incorporation of the software into industrial operating environments is discussed.

