REGIONAL EMPTY MARINE CONTAINER MANAGEMENT

by

NEHA MITTAL

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ABSTRACT OF THE DISSERTATION

Regional Empty Marine Container Management

By NEHA MITTAL

Dissertation Director:
Dr. Maria Boile

Empty container repositioning is one of the longstanding and ongoing issues in the containerized maritime trade. Even though it is a non-revenue generating, expensive and undesirable exercise, it is an integral part of an overall efficient global transportation system, which balances demand and supply of empty containers between regions. Empty containers are repositioned at three levels - global, inter-regional and regional-level. The focus of this dissertation is at the regional level of empty container repositioning.

Regional repositioning of empty containers involves empty container movement between regional importers, marine terminals, empty container depots, and export customers. This chain movement generates excessive unproductive empty vehicle miles in a region. The problem of empty vehicle miles travelled becomes more prominent when empty container depots are located close to the port and import and export customers are inland. Stakeholders incur large system costs in repositioning empty containers between the regional import-export business locations and the port/depots. Regions with high import activity are concerned with the increase in containerized trade volumes and the persistent trade imbalance because of the capacity shortfall at their existing depots.

This thesis addresses the above two regional concerns of excessive empty vehicle miles and empty container storage capacity shortfall by proposing an 'Inland-Depots-for-Empty-Containers (IDEC)' system. It recommends opening new empty container depots inland in the region, closer to high volume import-export customer clusters, in addition to the depots currently being located near the ports. The dissertation discusses the feasibility, viability, and effectiveness of the proposed system.

It develops mathematical models for the IDEC system to determine the optimal number and location of inland depots in a given region under deterministic and stochastic demand patterns. Exploiting the structure of the NP-hard problem, it develops a heuristic based on the randomized rounding algorithm to solve large scale, realistic depot-location problems. To implement a successful and sustainable IDEC system, it explicitly considers the varied perspectives of different maritime stakeholders involved in the container movement. Based on the models and quantitative analyses, it demonstrates that an IDEC system has great potential in improving regional empty moves, increasing both business profitability and social welfare simultaneously.

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DEDICATION

I take this opportunity to acknowledge the time, effort and love that my brother, Mr. Nitish Agrawal has always given me. Without his teaching in my childhood years, I would have never been able to build my foundation and interest in Science and Engineering.

I can't thank enough my husband Mr. Mohit Mittal, who gave me love, moral support, encouragement and always remained with me in times of good and bad. I am thankful to him for proofreading my paper drafts and encouraging me throughout the process of my PhD. My dissertation would not have been possible without his belief in me. I also admit the cooperation and patience of my 3-yr. old daughter, Ms. Piyali Mittal. Her love kept me motivated and going in the tough times.

Nothing would have been possible without my parents. Without their blessings and prayers, I would have never reached here…

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1 INTRODUCTION AND RESEARCH BACKGROUND

1.1 Maritime Transportation

Maritime transportation deals primarily with the movement of international freight and enables long distance goods movement at cheaper costs. Passenger movement is only a marginal 'leisure' function of the maritime industry today, serviced by cruise liners. Maritime trade is one of the oldest forms of trading. Egyptians were first to trade using sea and sail their ships in 3,200 B.C. Today the industry is well-developed and well-established in transporting goods across the globe and indeed provides the underpinning of a successful global economy.

1.2 International Freight Transport and Containerization

Recent globalization of the world economy has tremendously increased the exchange of goods all around the world. Increasing industrialization and liberalization of national economies has fuelled free trade and growing demand for consumer products. In search of economical and competitive manufacturing, production centers of most industries have rapidly shifted their basis beyond national borders. As globalization has developed, world trade and in particular sea-borne trade has grown rapidly in the past few decades and is predicted to grow even faster in the coming years. Maritime transportation provides a cheap mode for movement of freight over long distances. Containerization has revolutionized the maritime industry. It has greatly boosted the trade and improved the efficiency of transportation and handling of cargo. Prior to containerization, all products were moved in break bulk.

Malcolm McLean from New Jersey invented container shipping in 1930’s. Port Elizabeth in New Jersey was developed as the world’s first container port to implement McLean’s ideas. The first container ship sailed from Port Elizabeth, NJ to Houston in 1956 and a decade later, the container ship made the first transatlantic trip of containers from Newark, NJ to Rotterdam, Holland.

Since the beginning of containerization, international containerized trade has increased at a rate far exceeding that of maritime trade as a whole. In the last fifty years, maritime transportation and cargo handling have become much faster, resulting in increasing trade efficiency and productivity. It is estimated that today 90% of the world’s trade is moved by containers [1]. It is also estimated that presently the maritime industry carries about 71% of all international trade by share, 98% of global freight by volume and about 96% by weight, i.e., 6.4 billion tons of international trade. The total marine activity has reached over 25,000 billion ton-miles compared to 7,000 by rail and 3,000 by road per year [2].

It is believed that world trade and seaborne trade will continue to grow as demand for foreign-manufactured goods will grow. Trade boosts income and growth, and therefore jobs. However, the overall efficient maritime transportation system suffers from a few notable challenges; some of these are age-old and some have resulted due to the massive increase in the trade volumes in a relatively short period of time. Examples of issues that concern the industry are – (a) increasing gap between the capacity provided by the current maritime trade supporting infrastructure and the services demanded from it, (b) congestion at ports and at inland intermodal transportation networks, (c) environmental issues, (d) security, and (e) empty container repositioning.

This dissertation addresses the concern of empty container repositioning and aims to minimize the large system costs incurred in landside empty container movement. In this chapter, a brief introduction is provided on the evolution of the maritime industry, its key stakeholders and the current practices in repositioning empty containers. Existing inefficiencies in the container repositioning system are highlighted and a solution to strategically deal with the problem is proposed.

1.3 Empty Container Repositioning

Empty container repositioning is a non-revenue generating, expensive and an undesirable exercise. However, ocean carriers need to reposition empty containers to fulfill the empty container demand in a region where its supply is insufficient. At import locations a surplus of containers is generally available, while at export locations typically there is a deficit. Empty containers are repositioned at three levels global, inter-regional and regional [3] as shown in Figure 1.

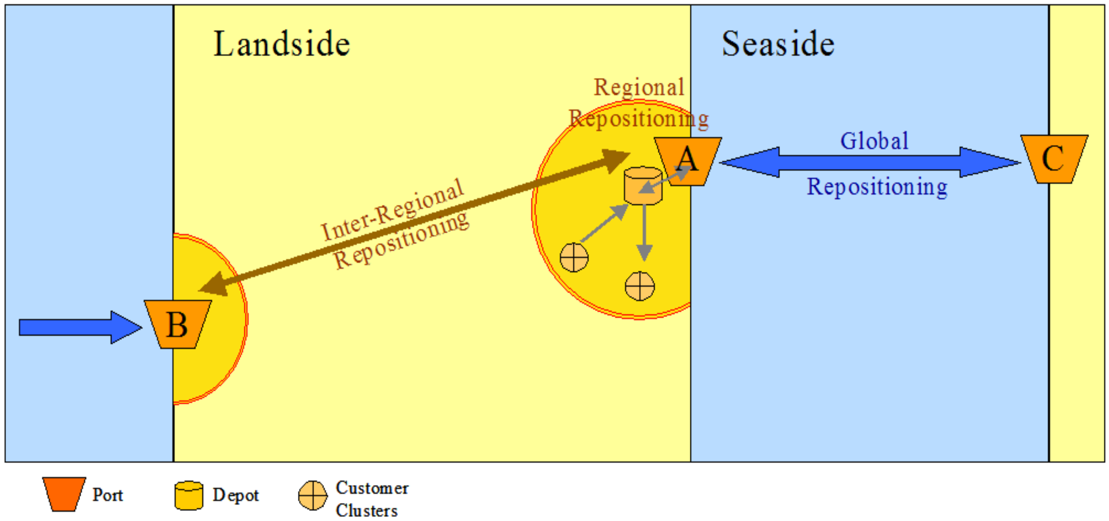


Figure 1: Empty Container Repositioning at Three Levels

On a global basis, empty containers are repositioned over sea between two foreign ports (indicated as locations A and C in Figure 1). For example, loaded containers from the East (South and Southeast Asia) (area C) arrive at the West (North America, Western Europe) (area A) and empty containers are repositioned back (Figure 2).

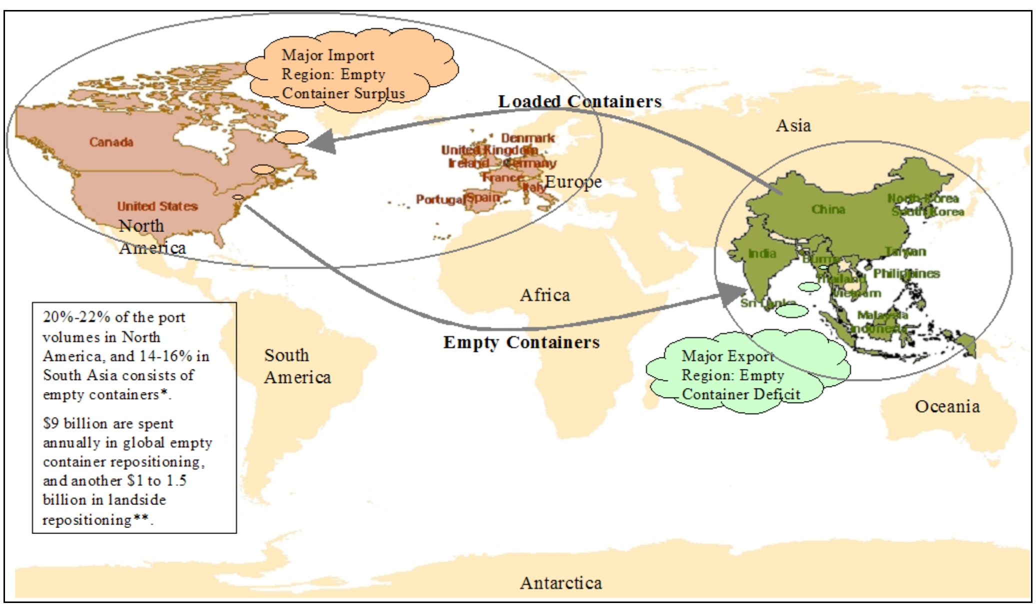


Figure 2: Current Practice in Global Container Movement

Source: *refers to Prozzi et al, TRR 1833, 2003 [4]; ** refers to Dynaliners Annual Report, 2006 [5]

In regions with high supply of empty containers (region A is marked as a surplus area for empty containers), ocean carriers reposition their empty containers to areas of high demand at large expenses, or if possible, off-hire surplus containers. Often times, they temporarily store containers in depots located in the surplus regions to allow some time before making any decision. On the other hand, in regions of high demand for empty containers (such as region C in this example), ocean carriers bring/import repositioned empty containers from surplus areas, lease or buy containers and sometimes form alliances and agreements to match their needs with other carriers. As noted in Figure 2, it is estimated that about $9 billion are spent annually in repositioning empty containers on the sea-side and if the inland haulage costs are added, the total costs would add another $1 to 1.5 billion [6].

At an inter-regional level, empty containers are repositioned over land (by truck or rail) between two regions, for example between region A and region B. This is often the case when loaded containers are imported in a region (port) that is different from their consumption region. In the U.S., a large percentage (over 60%) of the international marine containers moving into and out of the North Jersey region do not actually move through the region's marine terminals – containers are imported and exported via west coast ports (principally Los Angeles/Long Beach and Seattle/Tacoma), and moved to/from North Jersey via intermodal rail, double-stack trains [7].

At a regional level, empties are repositioned between regional importers, exporters, depots and the port within a region. In this case truck is the predominant mode for transporting containers. The drayage and terminal costs in short-haul rail often make rail an inefficient mode to transport [8]. Figure 3 shows the current practice in regional container movement.

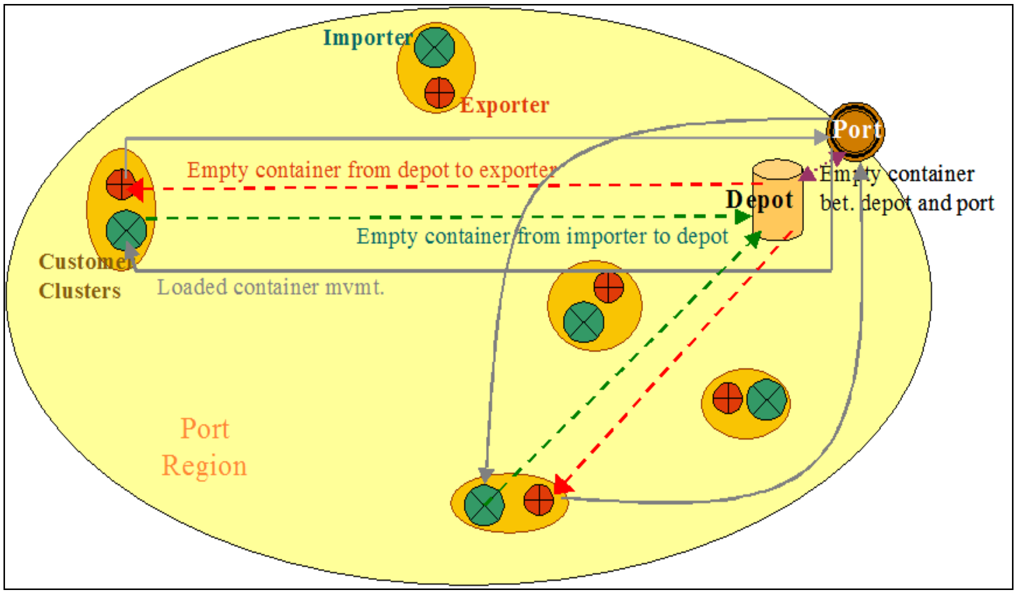


Figure 3: Current Practice in Regional Container Movement

This dissertation focuses on the regional empty container repositioning practice. It addresses the inefficiencies in the existing system and deals with the empty container storage capacity concerns in major import-regions.

1.4 Regional Empty Container Repositioning System

A port region typically consists of a port (marine terminals), empty container depots and import-export business locations, among which loaded and empty containers move. Under the current practice, empty container depots are typically located in or near the port area, while import-export businesses (warehouses/distribution centers) are rapidly moving inland [9].

When a ship arrives with loaded import containers and drops-off the containers at the port terminal, trucks typically haul these containers to their inland destinations (warehouses and distribution centers). After unloading at the import customer's site, the empty container is carried by a truck to a depot, where it is temporarily stored until it is repositioned overseas or it is repositioned within the region to fulfill an export demand. When an export customer demands an empty container, a truck carries the empty container from the depot to the customer. After loading, the customer sends the container to the port for export (Figure 3). This practice generates multiple empty vehicle miles. Further empty vehicle miles are generated because the truck that dropped off the loaded container rarely picks up an empty container on the return trip from the customer site. Bobtail trucks travel after dropping-off the loaded container and before they pick-up the empty at the import customers' site, and the same cycle repeats for the export customer. The practice becomes extremely inefficient when the distance and flow between the depots and regional customers increases.

The next sub-section presents the evolution of the current practice and discusses some of the reasons why this practice has sustained until today, even though it is inefficient and expensive.

1.4.1 Evolution of the practice

Traditionally, prior to the evolution of the third generation ports (prior to 1980), ports were the primary handling and service centers. Warehousing and other port related activities were located inside the port. Later, as the industry grew, activities such as distribution, repackaging, and reconsolidation started moving out of the port boundaries. As the space inside the terminal became inadequate, terminal operators started storing their empty containers at near-dock depots. This gave them the required space inside the terminal, while providing the visibility and asset control that their customers (shipping lines) expected. In order to address shipping lines' interests, empty containers were typically hauled back to the near-dock depots every time a customer supply or demand was generated in the region. Warehousing and other import-export businesses were initially located very close to the port due to the obvious conveniences. With neither the distance between the depot and the customers, nor the volume transported between them being large, empty vehicle miles traveled in the region were not prohibitive. This mode of operation slowly became an industry practice where, to this day, empty containers are still hauled back to the port or near dock depots.

Other important factors that contributed to the current practice include limited technology and Internet advancement, unavailability of modern services such as depot direct off-hiring offered by the terminal operators, ocean carriers' interest in keeping empty containers close to the port (for easy access and asset-visibility), and truckers being paid by the ocean carriers for making double moves. In the present era, the land near the port has become scarce and expensive, regional businesses are moving farther inland from the port, energy prices are high and advanced IT systems have developed that can better manage container movement. Empty container management patterns are changing and therefore, existing empty container depot system needs to be re-evaluated and possibly re-configured.

External factors that occur at global or national levels also influence regional practices. These factors include stakeholder interests, ocean carriers' changing business patterns (offering door-to-door service rather than traditional port-to-port service), fluctuation in the cost of building new containers (steel prices and production capacity), leasing and repositioning cost of containers, trade deficit, and competitive position of the region. These factors affect regional practices, measures, and policy decisions that are required to remain in sync with the external system requirements.

1.4.2 Problems with current practice

Ports, which were once responsible for urban growth, are at the urban centers today. The land near the port is scarce and expensive. Though empty container depots presently exist close to the port, regional authorities strongly discourage their expansion as well as the development of new such facilities near the port. Regional customers (warehouses/distribution centers) on the other hand are moving inland in search of cheaper and larger land parcels. This has created longer trips for the truckers every time they haul the empty container to-and-from the regional customers to the depots; resulting in excessive empty vehicle miles travelled, congestion and pollution in the port area. Congestion leads to higher cost of truck freight and service operations that negatively impact the manufacturing industry and the service sector. It is expected that by the year 2020, freight traffic will grow by 57% or more in the United States, [10] and that primarily the highway network will accommodate all this increased traffic. Long trips and high volumes will make empty truck miles reach extremely high levels in major port regions. With increase in volume and imbalance in trade, capacity at existing near-dock depots will also become incapable of handling and storing future empty container volumes. Most container depots in the NY/NJ region in the year 2002-03 had already experienced container inventories exceeding their reported capacities [11]. For such regions to remain competitive, an improved empty container movement is a priority.

1.5 Key Stakeholders in Empty Container Repositioning

Container movement comprises different sets of people, links and nodes, at each level. Direct and indirect stakeholders are involved, having varied interests, objectives and perspectives. Shippers, carriers, lessors, depot owners, port terminal operators, port authorities, truckers, railroads, brokers, freight forwarders, warehouse operators and other state and federal regulatory agencies and private entities are all players in the complex shipping industry. The process is extremely complex and dynamic in nature and the often conflicting interests of stakeholders make the overall container transportation and management very difficult.

The owners of containers are primarily ocean carriers and leasing companies. Traditionally, carriers and lessors have equally shared the world container fleet. However, in the past decade, the share of container ownership by ocean carriers has been increasing constantly. For ocean carriers, containers are considered as cargo-carrying equipment, while for leasing companies containers are considered as assets. Therefore, the way they handle them is different. It has been seen that in practice, it is the ocean carrier who does most of the empty container repositioning. Leasing companies often sign such agreements that enable them to balance their container inventory without having to reposition many containers. Leasing companies often state clause within their lease agreements that discourage carriers to off-hire containers at a place where the leasing company doesn’t want to receive them (at an empty container surplus area); they apply additional charges and allow only a very specific quota—a stated number of containers which a carrier can off-hire at a certain location per month. Thus, ocean carriers suffer a glut of containers in the surplus regions (North America and Northern Europe), requiring surplus inventories to be moved back empty. A few containers in the global fleet are also owned by depot owners. Depots play an important role in empty container repositioning. They primarily deal with empty containers and are responsible for empty container storage and repairs. In some cases, depots also buy empty containers and after performing repairs and modifications they sell them into the secondary market.

1.6 Global efforts and their effectiveness

Regional port authorities and industry stakeholders all around the world recognize the problem of empty container repositioning and the cost they incur under current practices. In efforts to optimize empty movements in real-time, recently the ‘street turn’ or Virtual Container Yard (VCY) concept has gained attention [12-14]. VCY provides a mechanism for shared resource information system to match empty container needs through the adoption of internet and new technology based information platforms. The approach is very promising, although issues such as the complex organizational structures (ownership mismatch, import/export timing, location and time mismatch, and off-hiring of leased containers), need to be overcome for such a system to achieve its full potential. [15-17].

In a significant trend to clear cargo while avoiding port congestion, inland ports and inland terminals are developed at several locations in North America and other places around the world [18-24]. Inland ports enable containers to quickly reach a deconsolidation facility, located inland away from the port. The inland facility and the port are connected by rail, and loaded containers travel to inland ports by rail. From there, containers reach their final destination by trucks. These projects require vast land, extensive rail network and strong financial budget for their development. Freight village [25, 26] is another concept that is gaining interest among regional authorities. These are defined areas/clusters of transportation logistics activity for import-export businesses. A freight village close to an inland port may prove to be an efficient way of managing loaded and empty containers in a region.

1.7 The Proposed Solution

In order to deal with the issue of excessive empty vehicle miles and capacity limitations at existing depot sites, this work proposes the development of ‘Inland-Depots-for-Empty-Containers’ (IDEC) system in regions with high trade volumes. The proposed system determines the optimal location of empty container storage depots inland in a region, closer to regional import-export customer clusters (with higher volume of supplies and demands), in addition to the depots being located close to the port. The objective of the inland depots is to minimize the total system cost in repositioning empty containers in the region (cost of opening new depots and moving containers between the depots and customers), while providing customers with the desired level of service. It is believed that inland depots will optimize empty container movements in the region, and provide region with the additional buffer storage for empty containers. Import containers will then be able to wait locally in a depot to match its corresponding export load.

The proposed inland depots are an intermediate solution between the current system and a fully operational and successful VCY system. Figure 4 illustrates these systems visually.

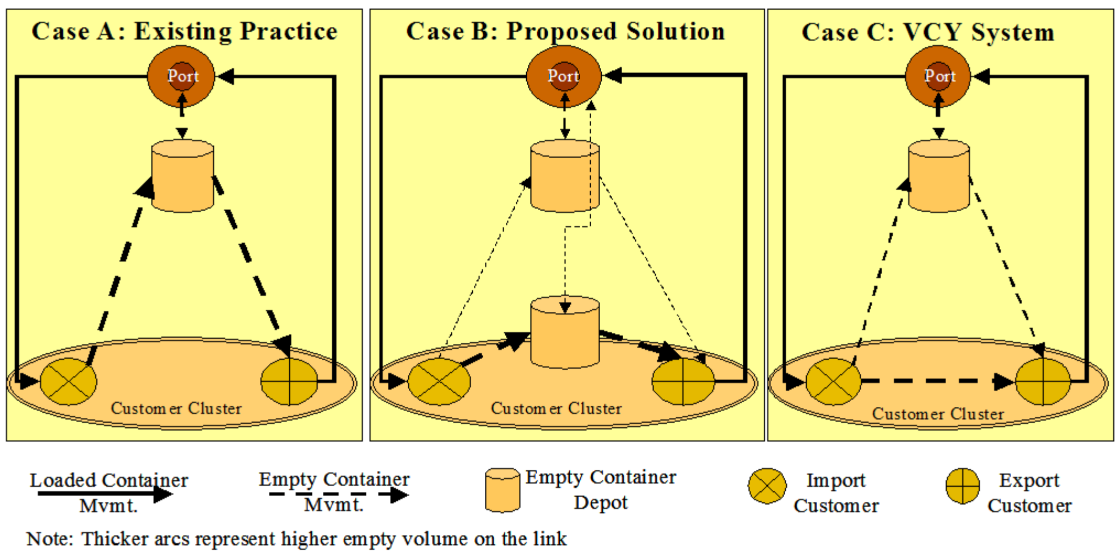


Figure 4: Empty Container Repositioning Scenarios

Case A represents the current empty container repositioning system at regional level. Here, depots are located close to the port and trucks haul empty containers back-and-forth between the depot and the customers' locations in the region. Case C illustrates a successful Virtual Container Yard system; where empty containers are matched between the supply and demand locations and fewer trucks haul empty containers to and from the depot. Case B is the proposed solution wherein depots are located inland and closer to customer locations with the aim to minimize empty vehicle miles travelled in the region.

The concepts described above have been developed within the context of re-examining the current practices and improving system efficiencies. The concept of inland depots for empty containers which is the subject of this dissertation is proposed within the same context. It aims to address the issue of excessive empty vehicle miles travelled and capacity limitations at existing depot sites. A set of inland depots for empty containers in regions with high trade volumes is proposed. The inland depots should be located closer to regional import-export customer clusters with high volume of supplies and demands. The objective of the inland depots is to minimize the total system cost in repositioning empty containers in the region (cost of opening new depots, which is typically higher closer to a port and moving containers between the depots and customers), while providing customers with the desired level of service. The proposed IDEC system will optimize empty container movements in the region, and will provide the region with the additional buffer storage for empty containers. An import container will then be able to wait locally in an inland depot to match its corresponding export load.

1.8 Viability and Feasibility of an IDEC System

While the proposed concept seems intuitive at first instance, factors such as ocean carrier interest in keeping empty containers close to the port (for their easy access and full-visibility) and the cost of building depots makes the decision complicated. However, advancement in technology and internet based software can now allow complete container visibility to ocean carriers from any location. A good balance between the number of containers stored in near-port and in inland depot locations can provide for meeting the ocean carriers' need for global repositioning. Looking at the present trend and forecasted growth in trade volumes, savings from the fewer empty vehicle miles may offset the cost of opening new depots. The proposed inland depots blend into existing practice in empty container repositioning. Inland depots will be a viable solution in cases where customers are clustered but do not have any empty container handling/storage facility near them. The increase in export demand in the US further supports this concept.

In the following chapters, quantitative and qualitative analyses have been carried out to further analyze the feasibility and advantages of the proposed system. Anticipated challenges in establishing an IDEC system are also discussed. The remaining chapters in this dissertation are organized as follows. Chapter 2 reviews pertinent literature on empty equipment fleet management and facility location analysis from the academic journals and industry reports. Chapter 3 develops mathematical formulation to optimally locate depots in a regional IDEC system under deterministic and stochastic demand patterns. Chapter 4 presents a case study analysis, where developed mathematical models are applied to the port region of New York/New Jersey. Chapter 5 discusses the need for a solution approach to solve large-scale depot location problems and presents the suggested approach. Chapter 6 carries out a multi-criteria decision making analysis for successfully and strategically implementing an IDEC system in a region, given the varied perspectives of the different stakeholders involved in empty container movement. Chapter 7 discusses the broader impact of an IDEC-system and Chapter 8 shows future research direction. Chapter 9 contains a list of references that helped in building this research work.

2 LITERATURE REVIEW

2.1 Empty Container Fleet Management

Numerous academic articles address empty equipment fleet management and depot location problems. Early instances in literature dealing with the empty fleet management problem are in context of railroads, where allocation and distribution of empty railcars is studied, given their supply and demand. Feeney [27], Leddon [28], and Misra [29] have some of the earliest work in scheduling empty freight cars. These formulations were static and deterministic. White [30] in the early '70's first formulated a dynamic transshipment network and applied it to the distribution of empty containers. Containerization began in 1956, which revolutionized the maritime industry. Frankel [31] was among the first to publish work on containerization and describe the practice. As advancements in maritime industry were made, the same empty equipment distribution problem from railroads was observed in the containerized trading. Jarke [32] studied container transportation logistics and insisted on the necessity for an efficient information and decision support system for managing containers. The problem of empty container management has been studied widely at the global level but very few researchers have focused on the national or regional level. At the global level, empty equipment management problem from a shipping line perspective [33-35], empty container allocation problem [36], effect of length of planning horizon on empty container management [37], profit optimization model for empty container repositioning and leasing for ocean-going ships [38], routing of ships for empty container repositioning taking into account both loaded and empty container legs [39] are present.

On the landside, most of the work in optimizing empty container movement has been performed by Crainic et. al. In 1987, they reviewed empty flows and fleet management in freight transportation [40]. In 1989, the first model with an objective to optimally find a set of 'hiring depots' to reduce the total system costs of moving empty containers for a particular shipping company [41] over land was formulated. Later, they studied the empty container problem in the context of managing land distribution and transportation operations for shipping companies [42]. Solution approaches to efficiently solve the problem formulated in [41], are provided in [43-46]. A study such as [47], has modelled the routing and scheduling of regional drayage operations, which involves movement of loaded and empty equipment between rail yards, shippers, consignees and equipment yards. To the best of the author's knowledge, no other study/model is proposed for empty equipment depot location and allocation problem. Other initiatives in separate problem context have addressed the depot/facility location problems [48-53], and proposed different solution approaches to solve the problem [54-61].

2.2 Depot Location

Location problems are one of the most widely studied problems in combinatorial optimization. In this dissertation we have a set of potential sites where new depots can be located, and a set of import-export customers who have requirements that are to be satisfied by the new depots. The basic components of the model are objective function (cost minimization), demand points (import-export businesses), potential locations, and the distance or time matrix.

Facility location problems are commonly formulated as location-allocation models that locate service facilities in a network and allocate demand to them. In these problems, the underlying network, demands, and distances (or related measures) are given in the problem definition. Technological, economic, geographic, political, and social factors also play a vital role in making location decisions.

Under 'depot location' problems, two optimization processes are most commonly seen:

1. A strategic-planning decision that optimizes the location and number of depots required to service the demand and supply points, and
2. A daily operational decision on the fleet management of vehicles and inventory hold

Substantial research has been done in the area of optimizing the day-to-day allocation decisions where researchers have proposed different deterministic and stochastic dynamic network models. In these models, the network is constructed from a pre-specified port or depot location with the given vehicle route schedules and capacities. The variables to optimize are the number of products transported in every itinerary and the amount to hold at each location.

Literature regarding the location-allocation of facilities for optimized movement and transportation of goods has developed different methods, algorithms and techniques to find the most optimal location and allocation for a facility. Facility location model for Inland Container Depots (ICD) has been given by Xu. Y. [54]. The formulation here combines the multinomial logit model of discrete choice analysis to describe the shipper's behaviors and preferences. Both the endogenous demand and market competitiveness are addressed, and one time period and one year are considered as the time horizon for locating facilities. Location-routing problem in context of locating distribution facilities and routing of vehicles from these facilities to its customers, in a distribution system is studied by Tunzen et al. [55]. The objective function minimizes the total cost of routing and acquisition of the vehicles and locating and operation of the depots. Stoker, [49] studies how a given number of depots for the distribution of goods can be located optimally so as to maximize profits with an acceptable return of investment given that the market has varying price and demand characteristics. Wang et al. [50] develops a bi-level depot location model to manage the resources needed for power restoration in an area which has experienced an outage. The first level in the problem locates depots and determines the amount of resources to be shipped from the depots to each restoration point in order to minimize the total transportation cost. The second problem adds new depots to an area where depots already exist, and makes the decision of whether or not it is necessary to establish new depots. Laporte et al. [56] gives an algorithm to minimize routing and operating costs for a depot location problem. Wu et al. [57] locates distribution centers (DC's) in a logistics environment so that an optimal number and location of DC's could be found with vehicle schedules and distribution routes to minimize the total system costs. Mary'n et al. [58] discusses the 'hub location' problem in transportation and telecommunication systems, where performance of the system is improved by using transshipment points (hubs) to collect and distribute the products. Sun [59] illustrates the importance of optimal facility location for an effective supply chain management and gives a Tabu search heuristic procedure to solve an uncapacitated facility location problem.

Table 1 summarizes the review of pertinent scientific articles and reports.

Table 1: Review of Pertinent Articles from the Literature

Author	Year	Problem Type	Planning Level	Problem characteristics	Base Model	Solution method
A) LITERATURE RELEVANT TO EMPTY CONTAINER MANAGEMENT						
Abarche et. al.	1999	Deterministic Dynamic Allowance of Empty Containers	Short-term	Satisfy customer requests and reposition empties for future demand	Decomposition based Dynamic model for deterministic problem	Primal decomposition algorithm
Boile et. al.	2006	Empty Container Management	-	Addressing regional empty Marine Container Management Problem	Theory	Policy recommendations
Chang et. al.	2006	Empty Container Reuse	Strategic	Optimize empty container movement regionally	Deterministic and stochastic empty container reuse problems	IP with Simulation
Chang et. al.	2007	Empty Container Substitution	Strategic	Optimize empty container movement regionally	Deterministic two-commodity substitution integer problem	Heuristic, using Branch and bound
Cheu et. al.	2003	Movers in container transportation	Operational	Estimate the total distance traveled by prime movers in transporting import and export containers between a port, warehouses, and container yards	Distance measuring from allocated depots	Gravity Model
Cheung and Chen	1998	Dynamic empty container allocation	Operational	Determine no. of leased containers reqd. and reposition empties	Two-stage stochastic network	Stocahstic quasi-gradient method
Choong et. al.	2002	Empty container management		effect of planning horizon length on empty container management for intermodal transportation networks	Integer Program	Optimization based solvers, AMPL w/ CPLEX

Author	Year	Problem Type	Planning Level	Problem characteristics	Base Model	Solution method
Crainic et. al.	2000	Transportation logistics and telecommunication applications	Strategic	Multicommodity location/allocation problem with balancing requirements	Network Design Formulation	Branch and Bound Algorithm with Parallelization strategy
Crainic et. al.	1993	Empty container Allocation	Operational	Allocation & Distribution	Minimum Cost Network Flow Problem	Dynamic deterministic modeling
Crainic et. al.	1997	Freight Transportation Planning and Operations	Strategic and Tactical	Main Issues in freight transportation and review of available solutions	Review/ Survey article	
Crainic et. al.	1989	Intercity freight transportation system	Strategic and Tactical	Locating empty vehicle depots in a freight transportation system	Simple Plant Location Problem	Linear Program
Dejax, Crainic	1987	empty flows and fleet management	Survey article			
Frankel E.G.	1968	Containerized Shipping	Theoretical			
Florez H	1986	Empty Container Repositioning		empty container repositioning and leasing problem for ocean-going ships	Profit optimization model	
Gendron, Crainic	1995	Managing fleet of vehicles for distribution and transportation forms	Tactical and Operational	Multicommodity location with balancing requirements	Multicommodity Uncapacitated Minimum Cost Network Flow Problem	Branch and Bound Algorithm with Dual ascent procedure
Gendron et. al.	1999	Transportation logistics	Strategic	Multicommodity location problem with balancing requirements	Multicommodity location problem with balancing requirements (MLB)	Tabu search heuristic based on exact neighbor evaluation
Hanh L.D.	2003	REPORT: Empty Container Logistics	Strategic	Empty container logistics practice		
Jarke M.	1982	DSS in container management	Strategic	Managing intercontinental container transportation		

Author	Year	Problem Type	Planning Level	Problem characteristics	Base Model	Solution method
Jula et. al.	2006	Empty Container Reuse	Strategic	Optimize empty container movement regionally	Network Problem	IP with Simulation
Lai et. al.	1995	Container Shipping logistical and allocation problem	Operational	Allocate empty containers, given the vessel schedule and capacity	Simulation Model	Heuristic to identify policies that may yield least cost
Lam, Lee, Tang	2007	Empty container Allocation	Operational	relocation of empty containers in two port- two voyage system	dynamic stochastic model	simulation based approach (temporal difference, TD) for average cost minimization
Li, Lieu, Leung, Lai	2004	Empty Container Management in a Port				
Li, Leung, Wu, Liu	2007	Allocation problem	Operational	multi-port empty container allocation problem	(u,d) policy model	Heuristic, using optimal policies to compute the specific allocation
Ognowski et. al.	2004	Developing Inland container ports	Strategic	Developing inland container depots for transportation, economic development and quality of life issues	Theory	Theoretical with a real life example
Prozzi J. et. al.	2003	Container Management	Information on freight industry and container mvmt.			
Perez, Holguin Veras	2005	Accumulation of Empty containers	Operational and Planning	multiperiod programming approach	LP, Container distribution model	Optimization based method, using AMPL
Resor and Balze	2004	Intermodal freight transportation	Strategic	Short-haul rail Vs. trucks	Facts and figures	
Shintani et. al.	2007	container shipping network design problem		design of container liner shipping service networks	Two-stage routing problem as LP	Genetic algorithm
Smilowitz	2006	Multi-Resource Routing Problem (MRRP)	Operational	Drayage Operations	MRR model	Column generation in B&B algorithm
Yahalom et. al.	2004	Empty Container Accumulation Problem	examines issues of empty container movement		Empty container logistics flow model and empty container flow model	

Author	Year	Problem Type	Planning Level	Problem characteristics	Base Model	Solution method
B) LITERATURE RELEVANT TO FACILITY LOCATION						
Baxter J.	1984	Facility Location	Strategic	Achieving local-optimal locations and then attaining a global solution.	Location Problem	Adaptive location-allocation method, using linear cost function
Drezner et. al.	2001	Waste collection services, septic tank cleaning, tree pruning etc.	Strategic	Location problem	Assignment Problem	Optimization based method
Eiselt	2006	Location Analysis	Strategic	locations of landfills and garbage transfer stations	Path based formulation, MIP	Optimization based method
Ghosh	2003	Facility Location	Strategic	Uncapacitated facility location	Uncapacitated FLP	Neighborhood Search
Gizelis et.al.	1979	Depot location for a manufacturing firm	Strategic	Location of depot	Location Problem	Simplified Optimization Algorithm
Greistorfer et. al.	2006	Facility Location		Filter and Fan approach		
Jasinka et. al.	1984	Sugar-beet distribution system	Strategic	Location of depots in a distribution system	Location-Transportation Problem	Mixed Integer Linear Program and heuristics
Laporte	1981	Depot location		minimizing routing and operations costs in depot location	Network Problem	
Marý´n et. al.	2006	Hub Location	Strategic	Uncapacitated multiple allocation hub location problem	Set Packing	Integer Linear Formulation
Misra	1972	Empty wagon disposition		Deterministic demand	network flow optimization problem	
Owen, Daskin	1998	Facility Location	Strategic	Review Article		
Perrier et. al.	2004	Winter maintenance planning	Operational	Location problem	Crew Assignment Problem	Optimization models and solution algorithms
Revelle, Eiselt	2004	Location Analysis	A synthesis and Survey			

Author	Year	Problem Type	Planning Level	Problem characteristics	Base Model	Solution method
Stoker	1980	Depot location in a distribution system		Determining the optimal number of depots acc. to market characteristics		
Sun	2006	Facility Location	Strategic	Facility location problem	Uncapacitated FLP	Tabu Search
Tuzun et. al.	1999	Distribution facility location	Operational	Location of the distribution facilities and the routing	Location Routing Problem	Two-phase tabu search
Wang et. al.	2004	Electric Power Restoration	Strategic	Facility location problem	Depot Location Problem	Linear Program solved using LINDO
Wang and Wang	2007	Empty Container Repositioning	Operational	Minimizing routing and operations costs in land carriage of empties	LP	Linear Program solved using Lingo 8.0
Wasner et. al.	2004	Depot for parcel services	Strategic	Multi-depot hub-location vehicle routing model	Hub Location and VRP	Heuristic Optimization
White W	1972	Dynamic distribution of empty containers	Operational			
Wu et. al.	2002	Transportation logistics	Strategic	Location Routing Problem considering multiple depots, multiple fleet types, and limited number of vehicles for each different vehicle type.	Location-Routing Problem	Decomposition-based method for solving the LRP; decomposes LRP into a LAP and a VRP. Uses SA.

2.3 Old vs. Proposed frameworks

Earlier models proposed operational tools to be run every few hours for determining the best set of ‘hiring’ depots from the set of existing depots, in order to minimize the cost (empty vehicle miles) of transporting empty containers in the network. This research presents a strategic model from a public-benefit perspective, where new depot locations are determined from a pre-specified set of potential sites. The introduction of new depots closer to customer clusters, not only reduces empty vehicle miles (and hence cost), it also adds capacity to store empty containers in the region with higher import activity. The model is formulated at a regional level, where inter-depot movements are not considered; inter-depot movements at regional levels are typically not performed in practice due to the costs involved (gate costs, handling charges) and due to the agreements that may exist between terminal operators and depot owners for storing their empties. The objective of this work is to provide a realistic and practical approach for empty container handling at regional level. The effort is first-of its kind that studies the regional empty container repositioning problem from a regional perspective as opposed to an individual shipping line perspective.

In the next chapter, mathematical models are developed and presented to evaluate the proposed system and analyze the benefits from the inland depot concept under deterministic and stochastic demand patterns.

3 MATHEMATICAL MODELING

To optimally locate new empty container storage depots in the proposed IDEC system, we formulate an inventory-based capacitated depot location problem under deterministic and stochastic demand patterns. A long-term (10-yr) planning horizon is considered for the problems. Section 3.1 presents the deterministic model, while Section 3.2 details the stochastic model.

3.1 IDEC System under Deterministic Demand Conditions

The model under deterministic demand conditions aims to minimize the total system costs (fixed cost of opening new depots + empty container transportation cost) in the time horizon, while satisfying the demand-supply volumes at the import and export customer and port nodes. A directed network graph G = {N, A} is considered, where N is the set of nodes and A is the set of directed arcs. Dummy subscripts 'i', 'j', 'k' and 'h' represent depot facilities, import customers, export customers and the port terminals, respectively in the region. Arcs represent the directed movements importer-to-depot (x_{ji}), depot-to-exporter (x_{ij}), depot-to-port terminal (x_{ih}), and port-terminal-to-depot (x_{hi})

3.1.1 Model Assumptions

- Empty containers do not move directly from an import customer to an export customer in the region.
- Empty containers do not move among depots in the region.
- All empty containers that come into a depot are assumed to arrive in the beginning of a time period *t*, while leaving containers are checked out of the depot at the end of period *t*.
- A linear cost-structure is considered for the transportation cost.

- Operational costs do not vary with the depot location given that they are located in the same geographical area.
- Customer clusters will continue to exist in the planning time horizon.
- Containers for a given ocean carrier can only be sent to/from a depot that serves the ocean carrier, according to the existing service agreements.
- The variables not in the formulation are implicitly taken to be zero.

3.1.2 Model Parameters

- Regional import-export customer demands and locations,
- Existing depot locations,
- Potential locations for inland depots,
- Distances between all depots (existing and potential) and customers,
- Location of the port, its distance from all depots and its empty container supply and demand requirements for global repositioning,
- Storage capacity at all depots, and
- Initial stock of containers at existing depots.

3.1.3 Model Notation

t = time periods in the study horizon T (t = 1…T)

D = set of existing depot owners in the study region (d Є D)

L = set of ocean carriers serving the region (l Є L)

F = set of depot facilities in the region

i_d^l = depot 'i' owned by depot owner 'd' that serves ocean carrier 'l' (i_d^l Є F, F = EF U NF),

EF = set of existing depot facilities (i_d^l Є EF)

NF = set of potential depot facilities (i_d^l Є NF)

Exp = set of export customers (empty container demand customers) (k Є Exp)

Imp = set of import customers (empty container supply customers) (j Є Imp)

H = set of port terminals

$S_j^{l,t}$ = Supply of ocean carrier *l's* empty containers from importer '*j*' in time period '*t*',

(j Є Imp, l Є L, t = 1… T)

$D_k^{l,t}$ = Demand of ocean carrier *l's* empty containers by exporter '*k*' in time period '*t*'

(k Є Exp, l Є L, t = 1… T)

$S_h^{l,t}$ = Supply of ocean carrier *l's* empty containers from port terminal '*h*' in time period '*t*', (h Є H, l Є L, t = 1… T)

$D_h^{l,t}$ = Demand of ocean carrier *l's* empty containers by port terminal '*h*' in time period '*t*' (h Є H, l Є L, t = 1… T)

$K_{i_d^l}$ = Storage capacity of the depot '*i*', owned by depot owner '*d*' that serves ocean carrier '*l*' (i_d^l Є F, d Є D, l Є L)

$f_{i_d^l}^t$ = Fixed cost of opening a depot '*i*' owned by depot owner '*d*' that serves ocean carrier '*l*', in time period '*t*' (i_d^l Є F, d Є D, l Є L, t = 1… T)

a^t = Cost of trucking a container (TEU) per mile, in time period '*t*'

$d_{i_d^l k}$, $d_{j i_d^l}$, $d_{i_d^l h}$ and $d_{h i_d^l}$ represent distances between respective nodes.

$c_{i_d^l k}^{l,t}$, $c_{j i_d^l}^{l,t}$, $c_{i_d^l h}^{l,t}$, $c_{h i_d^l}^{l,t}$ represents cost incurred in trucking a container between the nodes in time period '*t*', ($c_{i_d^l k}^{l,t} = a^t * d_{i_d^l k}$; $c_{j i_d^l}^{l,t} = a^t * d_{j i_d^l}$; $c_{i_d^l h}^{l,t} = a^t * d_{i_d^l h}$; $c_{h i_d^l}^{l,t} = a^t * d_{h i_d^l}$)

$N_{i_d^l}$ = Initial inventory of containers at depot '*i*' owned by depot owner '*d*' that serves ocean carrier '*l*' (i_d^l Є F, l Є L, d Є D)

Variables

$x_{j i_d^l}^{l,t}$ = Volume of ocean carrier *l's* empty containers, shipped from importer '*j*' to depot '*i*' (where '*i*' is owned by owner '*d*' and serves ocean carrier '*l*'), in time period 't'

(i_d^l Є F, d Є D, l Є L, j Є Imp, t = 1… T)

$x_{i_d^l k}^{l,t}$ = Volume of ocean carrier *l's* empty containers, shipped from depot '*i*' (where '*i*' is owned by owner '*d*' and serves ocean carrier '*l*') to exporter '*k*', in time period '*t*'.

(i_d^l Є F, d Є D, l Є L, k Є Exp, t = 1… T)

$x_{i_d^l h}^{l,t}$ = Volume of ocean carrier *l's* empty containers, shipped from depot '*i*' (where '*i*' is owned by owner '*d*' and serves ocean carrier '*l*') to port terminal '*h*', in time period '*t*'

(i_d^l Є F, d Є D, l Є L, h Є H, t = 1… T)

$x_{hi_d^l}^{l,t}$ = Volume of ocean carrier *l's* empty containers, shipped from the port terminal '*h*' to depot '*i*' (where '*i*' is owned by owner '*d*' and serves ocean carrier '*l*') in time period '*t*'

(i_d^l Є F, d Є D, l Є L, h Є H, t = 1… T)

$V_{i_d^l}^{l,t}$ = Inventory of ocean carrier *l's* empty containers at depot '*i*' (where '*i*' is owned by owner '*d*' and serves ocean carrier '*l*') in the beginning of time period '*t*'

(i_d^l Є F, d Є D, l Є L,$V_i^1 = N_{i_d^l}$, t =1…T+1)

$y_{i_d^l}^t$ = Binary, '1' if depot '*i*' (where '*i*' is owned by owner '*d*' and serves ocean carrier '*l*') is open at time '*t*'; '0' otherwise (i_d^l Є F, d Є D, l Є L, t = 1… T)

Objective function: Minimize total system costs in regional repositioning of empty containers

z = min (fixed cost of opening depots + empty container transportation cost in the network)

$$\sum_t \sum_{d\in D}\sum_{i_d^l\in F} f_{i_d^l}^t*(y_{i_d^l}^t - y_{i_d^l}^{t-1}) + \sum_t\sum_{l\in L}\sum_{j\in \mathrm{Im}p}\sum_{d\in D}\sum_{i_d^l\in F}(x_{ji_d^l}^{l,t}*c_{ji_d^l}^{l,t})) + \sum_t\sum_{l\in L}\sum_{d\in D}\sum_{i_d^l\in F}\sum_{k\in Exp}(x_{i_d^l k}^{l,t}*c_{i_d^l k}^{l,t}) +$$
$$\sum_t\sum_{l\in L}\sum_{d\in D}\sum_{i_d^l\in F}\sum_{h\in H}(x_{i_d^l h}^{l,t}*c_{i_d^l h}^{l,t}) + \sum_t\sum_{h\in H}\sum_{l\in L}\sum_{d\in D}\sum_{i_d^l\in F}(x_{hi_d^l}^{l,t}*c_{hi_d^l}^{l,t})$$

Subject to:

$$\sum_{d\in D}\sum_{i_d^l\in F} x_{ji_d^l}^{l,t} = S_j^{l,t}\ ; \qquad \text{for all } j \in \text{Imp}, l \in L, t = 1\ldots T \qquad (1)$$

$$\sum_{d\in D}\sum_{i_d^l\in F} x_{i_d^l k}^{l,t} = D_k^{l,t}\ ; \qquad \text{for all } k \in \text{Exp}, l \in L, t = 1\ldots T \qquad (2)$$

$$\sum_{d\in D}\sum_{i_d^l\in F} x_{hi_d^l}^{l,t} = S_h^{l,t}\ ; \qquad \text{for all } h \in H, l \in L, t = 1\ldots..T \qquad (3)$$

$$\sum_{d \in D} \sum_{i_d^l \in F} x_{i_d^l h}^{l,t} = D_h^{l,t} ; \qquad \text{for all } h \in H, l \in L, t = 1.....T \qquad (4)$$

$$V_{i_d^l}^{l,t+1} = V_{i_d^l}^{l,t} - \sum_{k \in Exp} x_{i_d^l k}^{l,t} - \sum_{h \in H} x_{i_d^l h}^{l,t} + \sum_{j \in \mathrm{Im}\, p} x_{j i_d^l}^{l,t} + \sum_{h \in H} x_{h i_d^l}^{l,t} ;$$

for all $i_d^l \in F, d \in D, l \in L, t = 1...T$ (5)

$$\sum_{l \in L} V_{i_d^l}^{l,t} + \sum_{j \in \mathrm{Im}\, p} \sum_{l \in L} x_{j i_d^l}^{l,t} + \sum_{h \in H} \sum_{l \in L} x_{h i_d^l}^{l,t} \le K_{i_d^l} * y_{i_d^l}^{t} ;$$

for all $i_d^l \in F, d \in D, t = 1....T$ (6)

$y_{i_d^l}^{t} \ge y_{i_d^l}^{t-1}$; for all $i_d^l \in F, d \in D, t = 2...T$ (7)

$y_{i_d^l}^{t} = 1$; for all $i_d^l \in EF, d \in D, t = 1... T$ (8)

$x_{j i_d^l}^{l,t} \ge 0$; for all $i_d^l \in F, j \in Imp, l \in L, t = 1... T$ (9)

$x_{i_d^l k}^{l,t} \ge 0$; for all $i_d^l \in F, k \in Exp, l \in L, t = 1..T$ (10)

$x_{i_d^l h}^{l,t} \ge 0$; for all $i_d^l \in F, h \in H, l \in L , t = 1... T$ (11)

$x_{h i_d^l}^{l,t} \ge 0$; for all $i_d^l \in F, h \in H, l \in L, t = 1... T$ (12)

$V_{i_d^l}^{l,t} \ge 0$; for all $i_d^l \in F, l \in L, t = 1...T+1$ (13)

$x_{i_d^l k}^{l,t}, x_{j i_d^l}^{l,t}, x_{i_d^l h}^{l,t}, x_{h i_d^l}^{l,t}$ are integers (14)

$y_{i_d^l}^{t} \in \{0,1\}$; for all $i_d^l \in NF, d \in D, t = 1... T$ (15)

Constraints (1) and (2) meet the empty container supply and demand requirements by the regional importers/exporters, in time period '*t*'. Constraints (3) and (4) meet the supply and demand volume requirement at the port '*h*' in time period '*t*'. Constraint (5) defines the beginning inventory for every ocean carrier at every depot in time period '*t*'.

Constraint (6) makes sure that if any volume is allocated from/to a depot, the depot is open; and also that the sum of incoming volume to the depot must meet the depot capacity limitation. Constraint (7) ensures that depot is opened only once, and once it is opened it remains open for all subsequent time periods. The selected inland facilities are truly in high-demand. Even if the demand falls significantly for these locations, they will still continue to have enough demand to warranting that they continue to remain open and operational. From a practical point of view, the monetary costs involved in reopening the facilities in a later time period offset the benefit from the facility when not needed. Constraint (8) keeps the existing depots open in the system, (9) through (13) are non-negativity constraints, and (14-15) are the integrality constraints.

3.2 IDEC System under Stochastic Demand Conditions

In a typical regional empty container repositioning network (Figure 5) empty containers return to the port/depot from import-customers, where they are stored temporarily. From there, containers are transported empty to regional exporter locations to carry out an export shipment or to marine terminals to fulfill a need for global container repositioning. The network has three important demand-supply nodes that influence the number and location of inland depots required in the region – (a) the empty container demand and supply for global repositioning at the port, (b) the empty container demand at the exporters' sites and (c) the supply of empty containers at the importers' sites. Uncertainty in demand and supply volumes exists at each of these three node types.

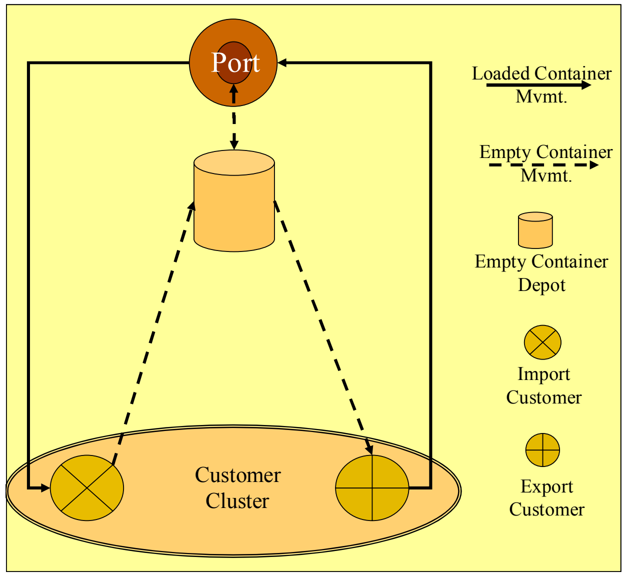


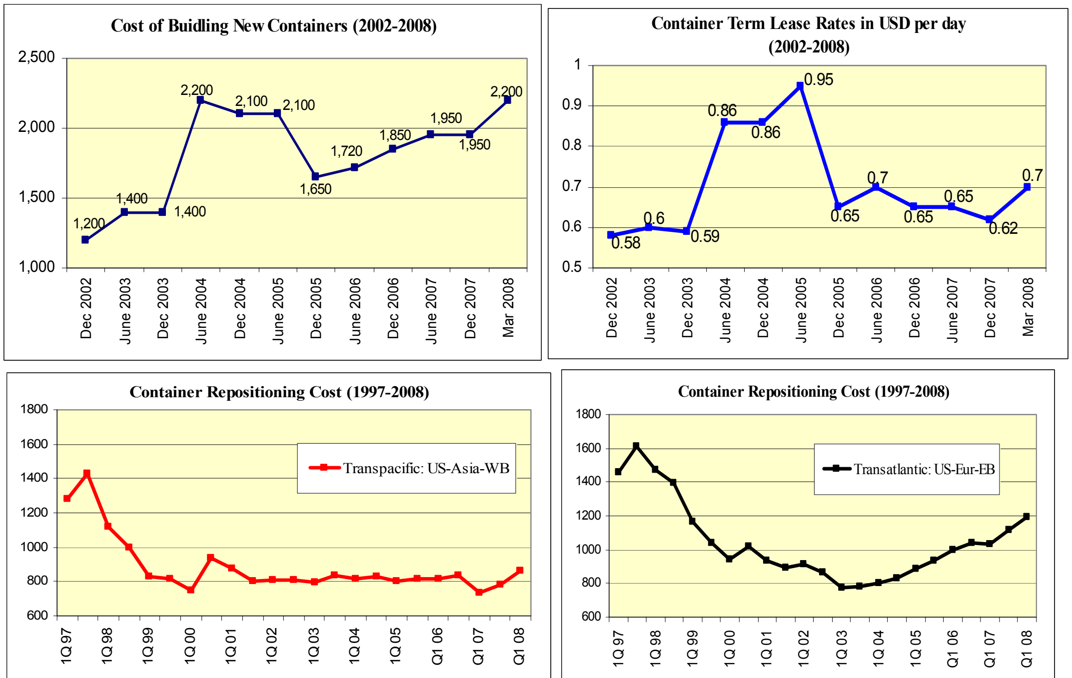
Figure 5: A Typical Current Regional Empty Container Repositioning System

3.2.1 Uncertainty in Empty Container Volume Handled at the Port

The volume of empty containers handled at a regional port is impacted by the global empty container repositioning requirements. Global demand and supply of empty containers at a port primarily depends on two factors - the cost of building or leasing new containers and cost of repositioning empty containers from a surplus to a demand region. Factors such as steel prices and energy prices impact the cost of building containers and repositioning them. Empty container repositioning is an expensive exercise both inland and by sea. In order to minimize the cost of managing the containers, container owners tend to follow the market trends. This creates uncertainty in empty container volumes handled at the regional ports.

To illustrate, until year 2004 the price of purchasing new containers was marginally higher than the cost of repositioning them from the U.S. East Coast to China. As a result, the option to purchase new containers seemed to be more appealing to the ocean carriers than moving empty boxes. This led to the reduced demand for empty containers at the port in areas with high import activity. However, as the steel prices hiked in early 2004 and new dry freight container prices increased by over 50% in the first half of the year [62], the trend reversed. Increased cost of building new containers with comparatively stable costs of repositioning empty containers generated ocean carriers' interest in repositioning large quantities of empty containers to the demand areas. As a result, port regions in the West began to observe high demand for empties at the ports and massive global repositioning. Recent increase in fuel prices along with the sustained high cost of building new containers present ocean carriers with a new challenge in optimizing their operations, especially with regards to empty container repositioning.

Figure 6 illustrates the variation and overall trend in container building and leasing costs, and cost of repositioning them from the U.S. The figure highlights large variances occurring in these factors, which in due course impact regional conditions.



Data Source: Containerization International

Figure 6: Some Major Factors Affecting Global Empty Container Repositioning

In this analysis the factors are not weighed independently but it is attempted to model the observed randomness of empty container volumes handled at the port and their probable impact on the depot location in the IDEC system.

3.2.2 Uncertainty in Empty Container Supply by the Regional Importers

High import container volumes are handled in the West (North America), primarily due to the outflow of manufacturing operations to countries in the East (Asia). As a result, regional importers in the West have customarily supplied large volumes of empty containers to the regional depots/ports. However, the recent devaluation of the U.S. dollar, the housing slump, and the high energy prices, which have squeezed consumers' wealth have slowed down this growth. The demand for imported goods has fallen. There has been a sharp decline in the growth of import volumes. In a regional empty container repositioning network, this translates to a reduction in the supply of empty containers from the regional importers to the depots. To support strategic infrastructure related decisions and account for the effect of uncertain regional empty container supply, we analyze the stochasticity in empty container supply volumes and their effect on strategic facility locations.

3.2.3 Uncertainty in Empty Container Demand by the Regional Exporters

Exports from North America have constantly declined in the past decade. With almost balanced trade in year 1997, export share fell to 32% in year 2006 [63, 64]. This constantly reduced the demand for empty containers regionally and depot owners started experiencing large inventories and capacity shortages in their facilities. Recently, however, reports state that "*U.S. manufacturers are now exporting more than 20% of all they produce, and total goods exports are growing by around 11% this year (2008) due to the global economic boom and a weaker U.S. dollar*" [65]. Trade journals in May 2008 indicated an empty container crunch experienced by exporters located in the inland U.S. [66]. This increase in exports translates to an increased demand for empty containers in a regional empty container repositioning network. These variations in the demand for empty containers make the decision on the supporting facility locations challenging.

Practitioners and academicians have analyzed location problems under uncertainty. However, due to the difficulty in solving most of the location problems to optimality, until recently the majority of research has been limited to static and deterministic problems [66]. Initial research dealing with input-parameter uncertainty in location problems were formulated as dynamic models. These models captured some of the real-world complexity, but assumed that input parameters are known or that they vary deterministically over time [67]. Stochastic location problems are relatively recent. These problems are based on either a probabilistic approach (considering probability distributions of the modeled random variables), or a scenario planning approach (set of possible future variable values) [68].

In this dissertation, the scenario-planning approach is used and a two-stage stochastic program with recourse is formulated to deal with the uncertainty in empty container demand volumes in the IDEC system. To the best of our knowledge, no other work has been performed in this field that addressed demand uncertainty using a two-stage-model-with-recourse. Stochastic programs with recourse provide an effective modeling approach when uncertainty can be modeled by a discrete set of scenarios [69]. The approach allows opening facilities in two stages - stage zero opens those facilities in the beginning of the time horizon that may work well under all possible realizations of the future scenarios, and stage one determines additional recourse facilities that should be opened later in the time horizon when more information is available. The problem is formulated with an objective to minimize expected system costs in locating facilities and transporting entities under stochastic demands. The two-stage stochastic analysis has seen several applications in various fields [70-72].

Figure 7 presents a simplified conceptual diagram of the proposed analysis. It considers three different scenarios and based on the probability of occurrence of each scenario, it indicates the number of facilities to be opened in stage-zero and stage one.

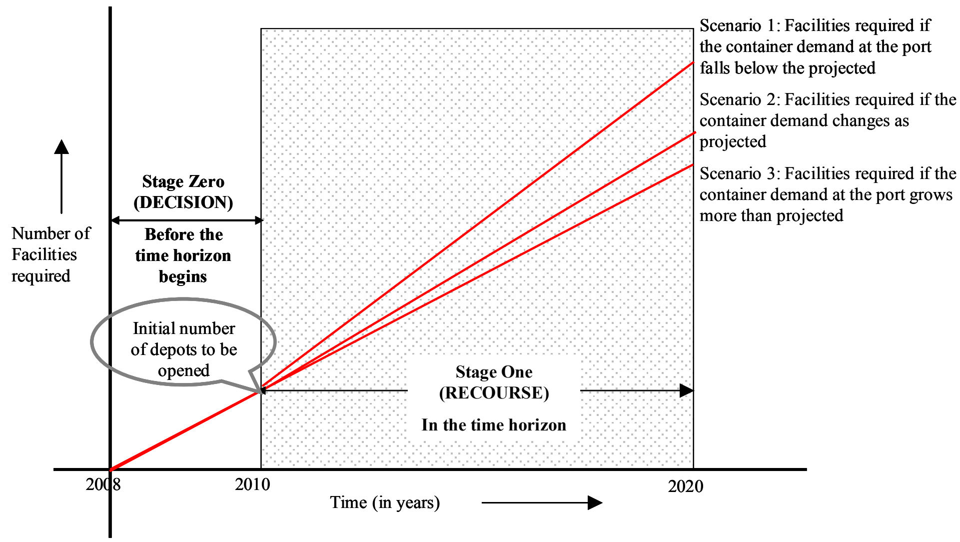


Figure 7: Conceptual Diagram for a Two Stage Stochastic Analysis

To locate depots under stochastic demand conditions, a two-stage stochastic program with recourse is developed to minimize the total system costs (fixed cost of opening new depots plus empty container transportation cost) in the time horizon. A scenario-based approach is taken for the stochastic modeling where discrete future scenarios are built and their probability is identified. A directed network graph G = {N, A} is considered, where N is the set of nodes and A is the set of directed arcs. Dummy subscripts '*i*', '*j*', '*k*' and '*h*' represent depot facilities, import customers, export customers and the port terminals in the region respectively. Arcs represent the directed movements importer-to-depot (x_{ji}), depot-to-exporter (x_{ik}), depot-to-port terminal (x_{ih}), and port-terminal-to-depot (x_{hi}).

3.2.4 Model Assumptions

- Empty containers do not move directly from an import customer to an export customer in the region.
- Empty containers do not move between depots in the region.
- All empty containers come into the depot at the beginning of a time period and leave to fulfill the empty container demand from the depot at the end of a time period.
- A linear cost-structure is considered for the transportation cost.
- Operational costs do not vary by the depot given that depots are located in the same geographical area.
- Customer clusters continue to exist in the time horizon.
- Containers for a given ocean carrier can only be sent to/from a depot that serves the ocean carrier, according to the agreement.
- The variables not in the formulation are implicitly taken to be zero.

3.2.5 Model Parameters

- Supply and demand of empty containers by importers and exporters under different scenarios,
- Geographic locations of importers and exporters,
- Geographic locations of existing depots,
- Potential geographic locations of inland depots,
- Location of the port and its distance from all depots,
- The empty container supply and demand from the port due to global repositioning under different scenarios,
- Distances between all depots (existing and potential) and customers,
- Storage capacity at all depots (existing and potential),
- Initial inventory of containers at existing depots, and
- Existing depot ownership, ocean-carriers serving the region, along with their agreements.

3.2.6 Model Notation

t = time periods in the study horizon T (t = 1…T)

D = set of existing depot owners in the study region (d Є D)

L = set of ocean-carriers serving the region (l Є L)

F = set of depot facilities in the region

i_d^l = depot 'i' owned by owner d that serves ocean-carrier l (i_d^l Є F, F = EF U NF),

EF = set of existing depot facilities

NF = set of potential depot facilities

Exp = set of export customers (empty container demand customers) (k Є Exp)

Imp = set of import customers (empty container supply customers) (j Є Imp)

H = set of port terminals

s = case scenarios, s = 1…N

P^s = probability of occurrence of a scenario *'s'*

$S_j^{l,t,s}$ = Supply of ocean-carrier l's empty containers from importer 'j' in time period 't', under scenario 's'. (j Є Imp, l Є L, s = 1…N, t = 1… T)

$D_k^{l,t,s}$ = Demand of ocean-carrier l's empty containers by exporter 'k' in time period 't', under scenario 's' (k Є Exp, l Є L, s = 1…N, t = 1… T)

$S_h^{l,t,s}$ = Supply of ocean-carrier's l empty containers from port terminal 'h' in time period 't', under scenario 's' (h Є H, l Є L, s = 1…N, t = 1… T)

$D_h^{l,t,s}$ = Demand of ocean-carrier's l empty containers by port terminal 'h' in time period 't', under scenario 's' (h Є H, l Є L, s = 1…N, t = 1… T)

$K_{i_d^l}$ = Storage capacity of the depot 'i' owned by depot owner d that serves ocean carrier 'l' (i_d^l Є F, d Є D, l Є L)

$f_{i_d^l}^t$ = Fixed cost of opening depot 'i' in time period t (i_d^l Є F, d Є D, l Є L, t = 1… T)

$f_{i_d^l}^0$ = Fixed cost of opening depot 'i' in stage 0 (i_d^l Є F, d Є D, l Є L, t = 0)

a^t = Cost of trucking a container (TEU) per mile, in time period t

$d_{i_d^l k}$, $d_{j i_d^l}$, $d_{i_d^l h}$ and $d_{h i_d^l}$ represent distances between respective nodes.

$c^{l,t}_{i_d^l k}$, $c^{l,t}_{j i_d^l}$, $c^{l,t}_{i_d^l h}$, $c^{l,t}_{h i_d^l}$ represents cost incurred in trucking a container between the nodes in a time-period, ($c^{l,t}_{i_d^l k} = a^t * d_{i_d^l k}$; $c^{l,t}_{j i_d^l} = a^t * d_{j i_d^l}$; $c^{l,t}_{i_d^l h} = a^t * d_{i_d^l h}$; $c^{l,t}_{h i_d^l} = a^t * d_{h i_d^l}$)

$N^l_{i_d^l}$ = Initial inventory of ocean-carrier *l's* containers at depot '*i*' owned by owner *d* that serves ocean-carrier '*l*' (i_d^l Є F, *l* Є L, *d* Є D)

Variables

$x^{l,t,s}_{j i_d^l}$ = Volume of ocean-carrier's *l* empty containers, shipped from importer '*j*' to depot '*i*'

(i_d^l Є F, *d* Є D, *l* Є L, *j* Є Imp, *s* = 1…N, *t* = 1… T)

$x^{l,t,s}_{i_d^l k}$ = Volume of ocean-carrier's *l* empty containers, shipped from depot '*i*' to exporter '*k*'

(i_d^l Є F, *d* Є D, *l* Є L, *k* Є Exp, *s* = 1…N, *t* = 1… T)

$x^{l,t,s}_{i_d^l h}$ = Volume of ocean-carrier's *l* empty containers, shipped from depot '*i*' to port terminal '*h*'

(i_d^l Є F, *d* Є D, *l* Є L, *h* Є H, *s* = 1…N, *t* = 1… T)

$x^{l,t,s}_{h i_d^l}$ = Volume of ocean-carrier *l's* empty containers shipped from the port terminal *h* to depot *i* (i_d^l Є F, *d* Є D, *l* Є L, *h* Є H, *s* = 1…N, *t* = 1… T)

$V^{l,t,s}_{i_d^l}$ = Inventory of ocean carrier's *l* empty containers at depot '*i*' in time '*t*'

(i_d^l Є F, *d* Є D, *l* Є L, *s* = 1…N, *t* =1…T+1) and $V^{l,1,s}_{i_d^l} = N^l_{i_d^l}$ at *t*=1

$y^0_{i_d^l}$ = facility '*i*' (owned by owner *d* that serves ocean-carrier *l*) to be opened in stage 0

$y^{t,s}_{i_d^l}$ = facility '*i*' owned by depot owner '*d*' and serviced by shipping line '*l*' to be opened in time '*t*' under scenario '*s*' in stage 1

The objective is to minimize total expected system cost in regional repositioning of empty containers in the time horizon under each probable scenario. The system costs include fixed cost of opening depots in stage-zero and stage-one, and repositioning cost of empty containers in the time horizon (T) under each probable scenario.

Objective function: z = min

$$\sum_{t} \sum_{d \in D} \sum_{i_d^l \in F} f_{i_d^l}^0 * y_{i_d^l}^0 + \sum_{s} P^s [\sum_{t} \sum_{d \in D} \sum_{i_d^l \in F} f_{i_d^l}^t * (y_{i_d^l}^{t,s} - y_{i_d^l}^{t-1,s}) + \sum_{t} \sum_{s} \sum_{l \in L} \sum_{j \in \mathrm{Im}\, p} \sum_{d \in D} \sum_{i_d^l \in F} (x_{ji_d^l}^{l,t,s} * c_{ji_d^l}^{l,t})) +$$

$$\sum_{s} \sum_{t} \sum_{l \in L} \sum_{d \in D} \sum_{i_d^l \in F} \sum_{k \in Exp} (x_{i_d^l k}^{l,t,s} * c_{i_d^l k}^{l,t}) +$$

$$\sum_{t} \sum_{s} \sum_{l \in L} \sum_{d \in D} \sum_{i_d^l \in F} \sum_{h \in H} (x_{i_d^l h}^{l,t,s} * c_{i_d^l h}^{l,t}) + \sum_{t} \sum_{s} \sum_{h \in H} \sum_{l \in L} \sum_{d \in D} \sum_{i_d^l \in F} (x_{hi_d^l}^{l,t,s} * c_{hi_d^l}^{l,t})]$$

Subject to:

$$\sum_{d \in D} \sum_{i_d^l \in F} x_{ji_d^l}^{l,t,s} = S_j^{l,t,s} ; \qquad \text{for all } j \in \text{Imp}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots \text{T} \qquad (1)$$

$$\sum_{d \in D} \sum_{i_d^l \in F} x_{i_d^l k}^{l,t,s} = D_k^{l,t,s} ; \qquad \text{for all } k \in \text{Exp}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots \text{T} \qquad (2)$$

$$\sum_{d \in D} \sum_{i_d^l \in F} x_{hi_d^l}^{l,t,s} = S_h^{l,t,s} ; \qquad \text{for all } h \in \text{H}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots\ldots \text{T} \qquad (3)$$

$$\sum_{d \in D} \sum_{i_d^l \in F} x_{i_d^l h}^{l,t,s} = D_h^{l,t,s} ; \qquad \text{for all } h \in \text{H}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots\ldots \text{T} \qquad (4)$$

$$V_{i_d^l}^{l,t+1,s} = V_{i_d^l}^{l,t,s} - \sum_{k \in Exp} x_{i_d^l k}^{l,t,s} - \sum_{h \in H} x_{i_d^l h}^{l,t,s} + \sum_{j \in \mathrm{Im}\, p} x_{ji_d^l}^{l,t,s} + \sum_{h \in H} x_{hi_d^l}^{l,t,s} ;$$

for all i_d^l Є F, d Є D, s = 1…N, l Є L, t = 1…T (5)

$$\sum_{l \in L} V_{i_d^l}^{l,t,s} + \sum_{j \in \mathrm{Im}\, p} \sum_{l \in L} x_{ji_d^l}^{l,t,s} + \sum_{h \in H} \sum_{l \in L} x_{hi_d^l}^{l,t,s} \leq K_{i_d^l} * y_{i_d^l}^{t,s} ;$$

for all i_d^l Є F, d Є D, s = 1…N, t = 1….T (6)

$$y_{i_d^l}^{t,s} \geq y_{i_d^l}^{t-1,s} ; \qquad \text{for all } i_d^l \in \text{NF}, d \in \text{D}, t = 1 \ldots \text{T}, s = 1 \ldots \text{N} \qquad (7)$$

$$y_{i_d^l}^{t-1,s} = y_{i_d^l}^{0}; \qquad \text{for all } i_d^l \in \text{NF}, d \in \text{D}, t = 1, s = 1 \ldots \text{N} \tag{8}$$

$$y_{i_d^l}^{t,s} = 1; \qquad \text{for all } i_d^l \in \text{EF}, d \in \text{D}, s = 1 \ldots \text{N}, t = 0 \ldots \text{T} \tag{9}$$

$$x_{ji_d^l}^{l,t,s} \geq 0; \qquad \text{for all } i_d^l \in \text{F}, j \in \text{Imp}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots \text{T} \tag{10}$$

$$x_{i_d^l k}^{l,t,s} \geq 0; \qquad \text{for all } i_d^l \in \text{F}, k \in \text{Exp}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1..\text{T} \tag{11}$$

$$x_{i_d^l h}^{l,t,s} \geq 0; \qquad \text{for all } i_d^l \in \text{F}, h \in \text{H}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots \text{T} \tag{12}$$

$$x_{hi_d^l}^{l,t,s} \geq 0; \qquad \text{for all } i_d^l \in \text{F}, h \in \text{H}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots \text{T} \tag{13}$$

$$V_{i_d^l}^{l,t,s} \geq 0; \qquad \text{for all } i_d^l \in \text{F}, l \in \text{L}, s = 1 \ldots \text{N}, t = 1 \ldots \text{T+1} \tag{14}$$

$$x_{i_d^l k}^{l,t,s}, x_{ji_d^l}^{l,t,s}, x_{i_d^l h}^{l,t,s}, x_{hi_d^l}^{l,t,s} \text{ are integers} \tag{15}$$

$$y_{i_d^l}^{t,s} \in \{0,1\}; \qquad \text{for all } i_d^l \in \text{NF}, d \in \text{D}, t = 0 \ldots \text{T}, s = 1 \ldots \text{N} \tag{16}$$

$$y_{i_d^l}^{0} \in \{0,1\}; \qquad \text{for all } i_d^l \in \text{NF}, d \in \text{D}, t = 0, s = 1 \ldots \text{N} \tag{17}$$

Constraints (1) and (2) meet the empty container supply and demand requirements by the regional customers, in time period '*t*' under scenario '*s*'. Constraints (3) and (4) meet the supply and demand volume requirement at the port '*h*' in time period '*t*' under scenario '*s*'. Constraint (5) defines the beginning inventory for every ocean carrier at every depot in time period '*t*' under scenario '*s*'. Constraint (6) makes sure that if any volume is allocated from/to a depot, the depot is open; and also that the sum of incoming volume to the depot must meet the depot capacity limitation. Constraint (7) ensures that a depot from set of NF is opened only once, and once it is opened it remains open for all subsequent time periods. Constraint (8) opens the necessary facilities from set of NF in stage one based on the stage zero analysis. Constraint (9) keeps the existing depots open in both the stage ‘0’ and ‘1’, (10) through (14) are non-negativity constraints, and (15-17) are the integrality constraints.

In the next chapter, Chapter 4, we apply these mathematical models to a case study and quantitatively analyze the feasibility and benefits from the proposed IDEC system.

4 CASE STUDY APPLICATION AND EVALUATION OF THE MODEL RESULTS

4.1 Study Region

To analyze the effectiveness of the proposed IDEC system, the mathematical models developed in Chapter 3 are applied to a region modeled after the port region of New York/New Jersey (PONYNJ). Four major states - Pennsylvania, New Jersey, New York and Connecticut are considered in the case study. We chose this region primarily due to (1) availability of data and (2) PONYNJ being the largest port on the east coast and the third largest in the United States, makes the region a good fit for a case study.

In the past decade, container throughput at the PONYNJ has more than doubled from 2.26M TEU in 1996 to 5.09M TEU in 2006, and forecasts indicate that container volumes will double again by 2020 and quadruple by 2040 [8, 11]. The port's 13-state region resides 38% of the U.S. population, and is the largest consumer market in the country [73]. The region has a high concentration of import-export businesses. New Jersey is the third largest commercial warehouser in the country, after Los Angeles and Chicago. The regional consumption and resulting number of loaded containers is very high. About 95% of all the containerized cargo that passes through PONYNJ is consumed within the 13-state region. Additionally, 60% of its demand is served by the West coast ports [7]. Loaded containers come via landbridge to the NY/NJ region. As the consumer market is within a relatively short distance from the port, trucks remain as the preferred and predominant mode for transporting containers. With significant imbalance between imports and exports, empty container repositioning, accumulation and storage, present serious issues in this region.

4.2 Empty Container Repositioning Practice in the Study Region

The NY/NJ region has seven major empty container depots [74]. Six of them are located within a 4-5 mile radius of the port. Warehouses and distribution centers are located inland and are moving farther away from the port in search of cheaper and bigger land spaces. The increase in consumer demand, trade volumes and respective location of the depots and customers have escalated empty truck miles traveled in this region. An article in June ‘06 [75] reported that more than 10,000 trucks travel on Interstate 287, 67,000 on the New Jersey Turnpike from Interchanges 7A through 18, and almost 23,000 trucks along Interstate 95 in New Jersey across the George Washington Bridge every day. Goods movement is essential to the quality of life in the New York metropolitan area and several factors explain why so many trucks move in it. But, with 30% of these trucks reported to be empty [76], the number of empty vehicle miles generated in this region is disturbing. The total annual cost of traffic congestion in New Jersey in lost time, operating cost, and fuel consumption is estimated to be approximately $4.9 billion [77]. In year 2002-2003, regional container depots, which report storage capacities of approximately 20,000 TEU showed inventory levels reaching 32,000 TEU [78] or 44,000 TEU according to another source [11].

4.3 Data Description

To determine the number and location of inland depots that may optimally serve the region in terms of managing and handling empty containers in a ten-year time horizon (yr. 2010-2020), the following data were gathered or generated based on information found in various sources. Import-export business locations in the four states were obtained from the PANYNJ (Port Authority of New York/New Jersey). The locations were later aggregated and customer clusters were formed. The locations of the port and existing depots were mapped. Potential sites for inland depots were identified from the DEP's Brownfield sites, based on their proximity to customer clusters in the region, highway and/or rail access, and a site size of atleast 15-acres. ArcGIS was used as the tool to map and evaluate these sites and select the potential locations. Figure 5 shows the case study network.

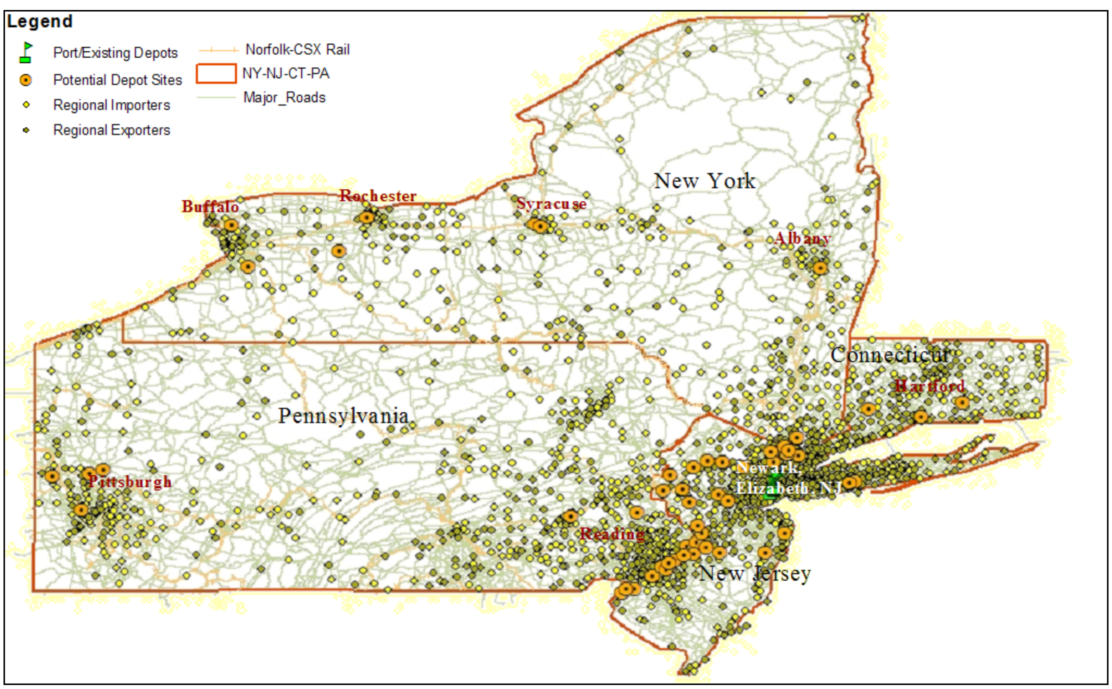


Figure 5: Case Study Region with Parameter Locations

Empty container supply and demand by regional customers for a 3-month time period was estimated based on information from the PANYNJ. Customer demand and supply volumes are projected in the study horizon by obtaining annual import-export volume data at the port and creating a trend in the growth of imports and exports. Using an ARIMA (Auto-Regressive Integrated Moving Average) forecasting model, volumes are projected by quarter for the time horizon.

- Annual import-export data from yr. 1997-2007 at PONYNJ were obtained from the MARAD website and were projected until the year 2020. Table 2 below shows the import-export volumes at PANYNJ for the ten year period.

Table 2: Import Export Container Volumes at PANYNJ (1997 – 2007)

Year	Imports	Exports	Percentage Growth in Imports	Percentage Growth in Exports
1997	1,057,769	680,844		
1998	1,212,717	671,551	14.65%	-1.36%
1999	1,362,438	664,750	12.35%	-1.01%
2000	1,511,579	688,765	10.95%	3.61%
2001	1,587,675	767,458	5.03%	11.43%
2002	1,879,455	747,661	18.38%	-2.58%
2003	1,964,759	838,277	4.54%	12.12%
2004	2,238,763	924,434	13.95%	10.28%
2005	2,438,367	978,254	8.92%	5.82%
2006	2,601,327	1,049,918	6.68%	7.33%
2007	2,640,303	1,253,189	1.50%	19.36%

Using trend analysis and ARIMA model for exports and imports, projections were made on an annual basis, which were then converted to a quarterly basis. Expert Modeler in SPSS was used to build the ARIMA model (p, d, q) for data projection. ARIMA (1, 2, 1) for exports and imports was used to build the projections. In ARIMA models, autoregressive term ‘p’ defines the number of autoregressive orders in the model. Difference (d) specifies the order of differencing applied to the series before estimating models. Moving Average (q) determines the number of moving average orders in the model. Moving average orders specify how deviations from the series mean for previous values are used to predict current values.

Distances between customers, ports and depots are calculated. A set of potential site for inland depots is identified based on the above mentioned criteria. Fixed cost of opening depots is estimated based on the land cost estimates for the identified potential Brownfield sites, their cleanup costs, equipment purchase costs and infrastructure costs.

- Land cost estimates for Brownfield sites were found in the range of $25,000 to $35,000 per acre [79].
- Cleanup costs on the Brownfield sites were found to vary from 20 to 100K per acre depending on the site contamination, clean-up procedures required and agencies involved [79].
- Equipment costs: It was found that typically a depot is equipped with 1 empty container handler and 1 forklift with extended forks, 2 steam clean machines, 6 MIG welding machines, hydraulic straightening equipment, guillotine, press brake, about 20 reefer points etc. [80], and the costs for each is approximately
    - Cost for empty container handler: $160,000 per piece
    - Cost for forklift: $50,00 per piece
    - Cost for Cleaning machine: $15,000 per piece
    - Cost for welding machine: $1,000 per piece

  - Cost for hydraulic straighter: $30,000 per piece
  - Cost for guillotine: $3,500 per piece
  - Cost for press brake: $5,000 per piece
- Additional cost for constructing and building initial infrastructure were estimated around $1M.

Storage capacity at depot sites is estimated based on the square footage area of the depot and a twenty-foot container (TEU) dimension, considering 5-high container stacks. Though existing depots report their capacity as 1-high stack storage capacity, to analyze and get results closer to the real world practice, a 5-high container stack is considered at all existing and potential depot sites [81]. Cost of transporting a container is taken from one of the studies previously performed [82]. This cost includes gasoline, vehicle wear-and-tear, congestion and air quality charges associated with transporting a container in urban areas.

4.4 Applying Deterministic Model to the Study Region

4.4.1 Analysis

To perform the case study analysis, three different depot owners were considered, where 'I' owns 3 existing facilities, 'II' owns 2 and 'III' owns 1 depot. Four different (major) ocean carriers (A, B, C, and D) are considered, where ocean carrier groups A and B are served by depot owner I, C is served by II, and D is served by III. Regional customer demand and supply volumes are distributed between the four ocean carrier groups.

Three cases are analyzed to determine the effectiveness of inland depots in reducing empty vehicle miles and increasing the regional capacity for future empty container handling. The base case A models the existing situation and evaluates present conditions when no inland depots exist. It assesses the capacity at existing depots to handle future empty container volumes, and calculates the cost of empty container repositioning. In this case, container ownership is considered by ocean carrier, and agreements between depot owners, terminal operators and ocean carriers are considered. Case B models the IDEC system considering the optimal number and location of inland depots, which are determined from a set of potential sites. The cost of repositioning empty containers is calculated and compared to the cost savings compared with the existing scenario, while maintaining customer service level. This case considers inland depots as satellite locations of the existing depots/depot owners. It considers that the same agreement, which exists between existing depots and ocean carriers, now applies to inland depots. Case C is similar to Case B. The main difference is that in this case, inland depots are considered to have open ownership, while existing depots still remain in agreements.

Problems are solved on an Intel® Pentium® Processor 4 with Mobile CPU 1.7GHz, 512MB RAM. Using the ‘branch and cut’ algorithm and CPLEX solver in GAMS 2.0.35.10, mixed integer problems are solved to optimality. Table 3 presents the results of the analysis for the three cases.

Table 3: Results for the Proposed IDEC System Using Deterministic Model

	Number of New depots opened in time horizon			Depots reach capacity at time			Total System Cost			Empty Vehicle Miles Traveled Regionally
Depot Owner →	I	II	III	I	II	III	I	II	III	
Case A: No Inland Depots	0	0	0	t=16	t=16	t=14	$1,063M at t16	$ 703M at t16	$ 335M at t14	705M miles by t16
Case B: Inland Depots as Satellite Locations	11	9	8	-	-	-	$ 561M at t16 $1,549M at t40	$ 446M at t16 $1,305M at t40	$ 243M at t14 $808M at t40	354M miles by t16 1,018M miles by t40
Case C: Inland depot have open ownership	21			-	-	-	$ 1,352M at t16 $ 3,977M at t40			407M miles by t16 1,229M miles by t40

The results indicate that in Case A that if the trends persists and container volumes increase as predicted, existing depot capacities will be reached by year 2014 (t=16) for depot owners I and II and by year 2013 (t=14) for depot owner III. The repositioning costs by that time will be $1063M for I, $703M for II and $335M for III to a total cost of $2151M by t=16. In Case B, 11, 9, and 8 new locations of ownership type I, II and III respectively would open up by t=40 (yr. 2020). The repositioning cost would be $561M for I, $446M for II, and $243M for III. Compared to Case A, the repositioning cost for I is reduced by 47% (~$500M) by t16, for II is reduced by 36% (~$250M) by t16 and for III is reduced by 27% ($92M) by t14. In Case C, 21 shared ownership facilities would be required. The repositioning cost till t=16 would be $1327M, a reduction of 38% (~$800M) compared to Case A.

In terms of empty vehicle miles traveled in the region to satisfy regional demand and supply for empty container volumes, results show that approximately 700M empty vehicle miles will be traveled in the region by t16 (year 2014) under present conditions. With the IDEC system, Case B shows a 49% reduction in empty vehicle miles by t16, as compared to Case A.

Comparing Case B with Case C, higher optimal costs are found in Case C. This seems counter-intuitive. Case C is less constrained compared to Case B given the fact that separate depot owners have been combined. However, Case B allows for individual depot owners to separately co-locate their facility at a potential site. Due to this, effective capacity of each potential location is 3 times the individual depot owner capacity. Case C, on the other hand, is considered as a "single" depot owner problem with capacity of the site 1/3rd that in Case B. This underlying difference results in higher costs and empty vehicle miles in Case C.

4.4.2 Evaluating robustness and effectiveness of IDEC system

The robustness and effectiveness of the IDEC system are evaluated under varying conditions of the model input parameters, such as demand-supply patterns, projected volumes, fixed cost of establishing inland facilities, capacity at inland facilities, and the change in transportation cost of containers.

Five main input parameters are considered to build different scenarios: variation in demand and supply patterns, demand and supply volumes, fixed cost of opening depots at potential sites, capacity at potential sites, and cost of transporting an empty container per mile. A base-case considers the following values for these input parameters: existing demand-supply patterns in the region, projected customer demand-supply volumes based on the historic trends, full fixed cost of opening inland depots (by location and acreage), storage and handling capacity based on the depot size and $3/TEU/mile as the cost of transporting empty containers through urbanized areas. Scenarios are built by varying one parameter at a time to estimate the sensitivity of the solution vis-à-vis a base case. Two separate analyses are made: the first examines the effectiveness of IDEC system over an existing depot system until the existing system experiences a capacity shortfall; the second examines the effectiveness of the IDEC system for different scenarios over the entire time horizon (t40), since IDEC is not restricted by the capacity. The base cases for the two analyses are labeled as Base case 1 and Base case 2 respectively. Scenarios are built to address the following key questions:

Scenario 1: What if there is a change in the distribution of demand patterns for empty containers *after* new inland depots have already been opened in the region? Will the new depots continue to be effective in reducing empty vehicle miles and total system cost? Will their location continue to be optimal?

Scenario 2: What if trade volumes do not grow as anticipated and remain steady? Under the case in which that volumes decrease, will the existing depots be sufficient to meet the demand? Although this scenario is not very probable, its analysis determines whether there is any significant benefit of putting into operation the IDEC system for such low volumes.

Scenario 3: What if stricter government regulations are introduced that result in higher cleanup costs (initial fixed costs double) at the potential sites. Will it still be worthwhile to open new inland depots with costs significantly higher than projected? What would be the effect if initial fixed cost in opening depots is reduced to half?

Scenario 4: Is it preferable to have more depot sites with smaller capacities or fewer sites with large capacities in the region? The potential sites chosen in the case study are all capacity constrained Brownfield locations. What if additional, Greenfield land could be obtained at the identified sites? In this Scenario capacities are doubled at all potential sites. This Scenario assumes that additional land may be obtained around the selected Brownfield sites, recognizing that the cost of this land may be higher than the cost of the Brownfield sites. For this purpose, this Scenario is modeled by scaling up the initial fixed cost of the additional land by 200%.

Scenario 5: Energy costs have been escalating during the past several years. What is the impact to the IDEC system if these costs continue to rise over the time horizon? What is the impact if these costs decrease? This scenario has been considered by modeling transportation cost at \$5/TEU/mile, \$3/TEU/mile (base case cost) and \$1/TEU/mile.

4.4.3 Results

<u>Scenario 1:</u> This scenario is analyzed to study the effect of new customer clusters in the region that may develop in the study period between yr. 2010-2020. Based on the study by NJDOT [81], two new customer cluster locations are introduced in the region; first in

year 2012 and the other customer cluster in year 2014. The analysis is run for the time horizon (yr. 2010-2020) with the same set of potential sites for inland depots.

Analysis showed that new customer clusters in the region would require three additional inland depot facilities to serve them optimally, but at the same time the region would still require the inland depots that were already opened in yr. 2010. Due to the existing customer clusters still remaining and their demand supply volumes still being valid, none of the earlier inland depot locations opened in yr. 2010 would be ineffective or unjustified.

The results for Scenarios 2 through 5 are summarized in Tables 4 and 5. Table 4 presents the savings in empty vehicle miles and total system costs for scenarios 2, 3 and 5 from an inland depot (IDEC) system over the existing depot system until existing system falls short of capacity. As Scenario 4 only analyzes a capacity-unrestricted IDEC system over a capacity restricted IDEC system, it is not applicable to Table 4. (Note: To reduce the number of cells in each table and understand the collective data, total system costs and empty vehicle miles traveled are presented as aggregate of all depot owners and ocean carriers.)

Table 4: Benefits from IDEC System until the Existing System shortfalls on Capacity

Variations in Input Parameters			Existing	IDEC	% Change from the Existing system under each scenario
Base Case1: (Given input parameters and shortfall in t16)	Capacitated $3/TEU/mile Full Fixed Cost	EVMT	700M	351M	50% (↓)
		Total System Cost	$2,101M	$1,250M (18)	40% (↓)

Variations in Input Parameters			Existing	IDEC	% Change from the Existing system under each scenario
Scenario 2: Change in trade volumes (No shortfall until t40)	Volumes remain static	EVMT (t40)	1,962M	695M	65% (↓)
		Total System Cost (t40)	$5,888M	$2,325M (22)	60% (↓)
	Volumes decrease: Projected vol. drop to 20%	EVMT (t40)	516M	323M	37% (↓)
		Total System Cost (t40)	$1,549M	$1,148M (16)	26% (↓)
Scenario 3: Change in Fixed Costs (shortfall in t16)	50% of Base	EVMT	700M	334M	52% (↓)
		Total System Cost	$2,101M	$1,115M (20)	47% (↓)
	200% of Base	EVMT	700M	447M	36% (↓)
		Total System Cost	$2,101M	$1,627M (13)	22% (↓)
Scenario 5: Change in Transportation Costs (shortfall in t16)	$1/TEU/mile	EVMT	698M	406M	42% (↓)
		Total System Cost	$698M	$537M (12)	23% (↓)
	$5/TEU/mile	EVMT	698M	272M	61% (↓)
		Total System Cost	$3,490M	$1,613M (23)	54% (↓)

(Note: EVMT represents Empty Vehicle Miles Traveled,
(Numbers in the parenthesis show the number of new facilities opened)

Table 5 presents a comparative analysis between the IDEC system (Base case 2) and cases in which base input parameters are changed (new IDEC system) over the study horizon (t40). Scenarios 3, 4 and 5 are shown in Table 5. Scenarios 1 and 2 are not included in Table 5 as Scenario 1 only evaluates the robustness of the inland depots when new customer clusters develop in the region, while Scenario 2 only compares an existing system with the IDEC system.

Table 5: Comparison in miles and costs in the time horizon (t40)

Variations in Input Parameters			New IDEC System	%Change from Base Case 2
Base Case 2: analyzed until t40		EVMT	1,118M	
		Total System Cost	$3,662M (28)	
Scenario 3: Change in Fixed Costs (t40)	50% of Base	EVMT	1,107M	1% (↓)
		Total System Cost	$3485 (29)	5% (↓)
	200% of Base	EVMT	1,138M	2% (↑)
		Total System Cost	$3916M (27)	10% (↑)
Scenario 4: Change in Capacity (t40)	200% of Base	EVMT	1,169M	4.5% (↑)
		Total System Cost	$5159M	42% (↑)
Scenario 5: Change in Transportation Costs (t40)	$1/TEU/mile	EVMT	1,184M	6% (↑)
		Total System Cost	$1438 (23)	61% (↓)
	$5/TEU/mile	EVMT	1,117M	0%
		Total System Cost	$5907M (29)	61% (↑)

(Note: EVMT represents Empty Vehicle Miles Traveled,
Numbers in the parenthesis show the number of new inland depot facilities opened)

Scenario 2: If trade volumes do not grow as projected and they either remain the same or decrease, analysis shows that existing depots will not experience a capacity shortfall in the study horizon (t40) under both cases. However, even when additional capacity will not be a requirement, it is found that opening inland depots will significantly reduce empty vehicle miles traveled and total system costs in regional empty container repositioning. From Table 4, when trade volumes remain static, opening inland depots would save 60% (1267M) in empty miles and 65% ($3563M) in costs by t40, over the existing system. When trade volumes drop to 20% of the projected volumes, savings from inland depots are still significant at 37% (193M) in EVMT and 26% ($401M) in total system costs by t40.

Scenario 3: In case the government provides incentives or shares the initial fixed cost in opening inland depots, analysis from Table 4 shows that when fixed costs are reduced to half, inland depots save 47% ($986M) in total system costs and 52% (366M) in empty vehicle miles traveled by t16 over the existing depot system. At t16, existing system experiences shortfall in capacity and inland depots will be needed to meet additional capacity requirements in the region. When compared the savings over the time horizon (t40), analysis from Table 5 shows a reduction of 5% ($177M) in total system costs and 1% (11M) in empty miles, when fixed costs are halved.

On the other hand, if the government introduced tougher laws for Brownfield redevelopment, and fixed cost of opening inland depots doubles, Table 5 shows that the region would still save 36% (253M) empty vehicle miles and 22% ($474M) in system costs from inland depots over the existing depot system by t16. Over the time horizon (t40), when compared from to Base case 2, Table 5 shows that total system costs would increase by 10% ($254M) and empty vehicle miles traveled by 2% (20M) in the region, due to the now higher fixed cost of opening the new facilities now.

In summary, the analysis shows that even when the fixed cost of opening new depots increase by 100% of the estimated, there would still be significant savings from the IDEC system, and the cost and empty miles would only increase slightly when compared to Base case2.

Scenario 4: In case the region decides to increase the available capacity (by making Greenfield space around Brownfields available) at all potential inland locations for empty container depots, analysis from Table 5 shows that both the total system costs and empty vehicle miles traveled will increase. This increase is attributed to the higher fixed cost (due to purchasing expensive clean land that also results in fewer new depot locations) and longer distances traveled by empty containers to reach their nearest serviceable depot in the region. The system costs increase by 42% ($1497M), and empty vehicle miles by 4.5% (51M).

Scenario 5: In the rare event that transportation costs reduce to $1/mile/TEU, Table 4 shows significant savings from IDEC over the existing system; 42% (292M) savings in empty miles and 23% ($161M) in total system cost by t16. When transportation costs increase to $5/mile/TEU; as one would expect, higher savings are observed; empty vehicle miles traveled reduce by 61% (426M) miles and total system costs by 54% ($1877M) over the existing system by t16.

When studied in the time horizon (t40) and compared with Base case 2, Table 5 shows that with $1/TEU/mile as the transportation cost, 61% ($2224M) savings are observed in the overall system costs. Even as fewer facilities open and there is a reduction in transportation cost, there is an increase in the empty miles traveled in the region by 6%

(66M). Since it becomes cheaper to move containers while the fixed cost remains the same, the system accommodates the empty container repositioning with the available capacity at fewer locations, but higher EVMT. When transportation costs increase to \$5/mile/TEU, system costs increase by 61% (\$2245M) from the Base case 2 as more facilities open to reduce the transportation cost in the system. Empty vehicle miles traveled in the region remain almost the same as in the Base case 2 when an additional depot is opened and container repositioning mileage is minimized.

4.4.4 Discussion and Conclusion

This section examined the issue of inland empty container depot development in major importing regions with increasing trade volumes and trade imbalances. It presented a strategic model from a public-benefit perspective, where new depot locations are determined from among an identified set of potential sites. Various scenarios of depot ownership and ocean carrier – depot owner agreements are examined. The results indicate the potential of inland depots to reduce empty vehicle miles traveled and associated costs, and improve the system's efficiency.

The advancement in technology and the Internet, and recent services such as 'depot-direct off-hiring' services offered by most terminal operators in the region strongly support inland development. The concept of inland empty container depot is more attractive and promising in the long term. In the short term the concept may seem costly to the parties involved, however when viewed in the long-term, congested highways and marine terminals, decreasing system efficiency and increasing cost of repositioning empty containers over land, with the consideration of the associated external cost, would justify the costs of building new inland depots.

Considering the anticipated increase in trade volumes and the chronic and evolving imbalance of global trade, the proposed system seems to be a promising solution in addressing the regional empty container management problem, meriting further consideration.

The inland empty container depot system (IDEC) has been shown to significantly reduce empty vehicle miles traveled and total system costs in regional empty container repositioning practice, yielding benefits to the individual stakeholder groups involved and the region as a whole. Earlier analysis showed that with the current projected trade volumes, existing depot facilities in the region, under conditions considered in the case study, would experience a capacity shortfall after year 2014. It also showed that even if capacity is not considered a constraint, inland depots would still significantly reduce empty vehicle miles and total system costs. The average trip length in the case study region reduces from 58.5 to 30.3 mile per trip in the first four years with inland depots operational. These average trip lengths would further decrease, as the volumes would grow in the study horizon.

The sensitivity analysis shows that the model and its solution are robust under varying input parameter conditions. After solving and testing the scenarios, the following recommendations and conclusions can be drawn:

- A change in the distribution of demand patterns (when new customer clusters develop in the study horizon at probable locations in the region) show that return on investment from inland depots opened in the beginning of the study horizon will continue to be realized even when new customer clusters develop later in the horizon. The analysis showed that though additional inland depots will be required to service new clusters at minimal system costs, none of the initial inland depot locations will be unproductive or unjustified.
- Even if the marine trade volumes do not grow as projected and they remain static or even decrease, inland depots will still result in significant system cost and empty vehicle mile savings. Inland depots will not be required in these scenarios to meet the current capacity concern at existing depots, and existing depots will be able to handle and store future empty container volumes. However, the savings in the overall system cost and empty vehicle miles traveled in the region would still demand and justify the opening of inland depots.
- Analysis shows that it will be prudent for the region to open more capacity-restricted inland depots on available Brownfield sites than choosing fewer capacity-unrestricted sites. Due to the high cost in purchasing clean sites and fewer depots in the region, both the system costs and the empty vehicle miles traveled in empty container repositioning practice would increase.
- As expected, if fixed cost of opening inland depots is halved of the current estimated cost, regional costs and empty vehicle miles traveled in the region would reduce proportionally. With lower fixed cost (if feasible) and higher number of inland depots opened in the region, associated costs with empty container repositioning would

reduce by 47% and empty miles by 52% over the existing depot system in the first few years (yr. 2010-2014).

- On the other hand, if fixed cost of opening inland depots doubles, fewer depots would open in the region, resulting in higher system cost and higher EVMT over Base case2, but still significantly lower than the existing depot system.
- If the transportation cost drops to $1/TEU/mile, the region would observe fewer inland depot requirements. Analysis shows that even though fewer inland facilities will be required, they will be essential. Compared with the existing system (Base case 1), inland depots would reduce the system cost by 23% and empty vehicle miles by 42% between the year 2010 and 2014. Comparing with Base case 2, system costs will reduce but empty vehicle miles traveled in the region would increase in the study horizon.
- With transportation costs increased to $5/mile/TEU, a higher number of inland depots will be required in the region to minimize system costs and empty vehicle miles in the region. As compared to the existing system, inland depots would then reduce costs by 54% and empty vehicle miles by 61% between the year 2010 and 2014. Comparing with Base case 2, system costs will increase and empty vehicle miles traveled in the region would remain almost the same in the study horizon.

Using a mathematical model and data from a case study, it is shown that the economic benefits of the IDEC system can be significant. Further, the analysis demonstrates that these benefits will continue to be significant even if the input parameters change drastically.

4.5 Analyzing Stochastic Demand Patterns in the Study Region

For the analysis, three existing regional depot owners are considered, where depot owner 'I' owns 3 existing depots, 'II' owns 2 and 'III' owns 1 depot. Four ocean-carrier groups (A, B, C, and D) are assumed to serve the region, where ocean-carriers A and B are served by depot owner I, C is served by II, and D is served by III. Regional customer demand and supply volumes are distributed across the four ocean-carrier groups (Ocean carrier A has 28% share, B has 22%, C has 32% and D has 18% share). It is assumed during the analysis that the new inland depots will be satellite locations of the existing depots/depot owners, and that inland depots will follow the same contractual agreement that exists between existing depots and ocean carriers.

To analyze probable randomness at the port and customer sites in the regional empty container repositioning network and their influence on the depot location, the nodes are studied independently. While it is possible that change at some of these nodes may occur in-combination or have an interdependence (for example, it is possible that a surge in imports may at the same time enable a large scale empty container repositioning from the region due to the larger unused capacity of the bigger vessels serving the region), we considered the nodes independently to study their individual effect.

4.5.1 Analyzing uncertainty in empty container demand at the regional port

To analyze the probable randomness in empty container volume handled at the port, we gathered data from the past decade on empty container volumes (total TEU handled minus total loaded TEU handled) handled at the Port of New York/New Jersey (PONYNJ). We assumed this volume to represent the demand of empty containers at the port, since it is a known fact that in this region (NY/NJ) a large percentage of empty containers handled at the port is the volume that is loaded on the outbound vessels. Figure 8 shows the data. A trend line is fitted on the data based on the statistical measures of mean squared error, mean absolute error, mean absolute percentage error, and mean percentage error.

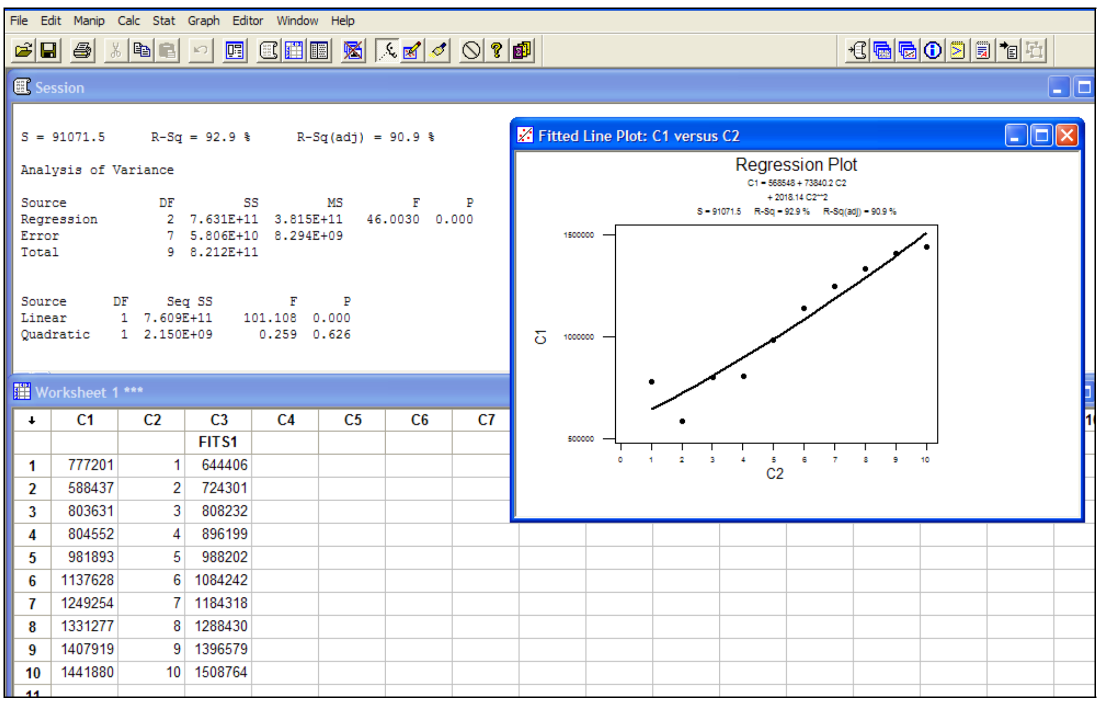


Figure 8: Empty Container Volume Handled at the Port of New York/New Jersey

The fitted line equation was obtained as:

$Y = 568{,}548 + 73{,}840.2X + 2{,}018.14X^2$,

Standard deviation = 91071.5 TEU;

i.e., μ = 568,548 and σ = 91,071.5 (one standard deviation (s.d.) was approx. ~ 15% of the mean).

Based on these statistics, we built the following discrete scenarios to incorporate the stochastic demand volume variations observed at the port:

- There is 7/10 probability that empty container demand will grow as predicted, i.e. within the ($\mu \pm \sigma$)
- There is a 2/10 probability that empty container demand will fall by more than one s.d. (more than 15%) but not more than two s.d., i.e. between [(μ-σ), (μ-2σ)] of the predicated volume.
- There is 1/10 probability that empty container demand will grow by more than one s.d. (more than 15%) but not more than two s.d., i.e. between [(μ+σ), (μ+2σ)] of the predicted volume.

4.5.2 Analyzing uncertainty in empty container volumes at the customer sites

To analyze the container demand-supply volumes at the importer-exporter sites in the region, we performed a similar analysis at the customer nodes. The data showed no significant fluctuation/spike in the past decade (variations were found within one standard deviation and $\pm$ 1-2% of the mean). For the two node types, the supply (loaded imports) and demand (loaded exports) of empty container volumes remained within one standard deviation from the mean. For this reason, we only focus on and analyze the port node.

4.5.3 Two-Stage Stochastic Analysis

As a first approach to analyzing stochastic demand volumes, we solved the following three cases independently - (1) demand volumes stay within the prediction range (2) demand for empty containers falls by more than one standard deviation or, (3) demand grows by more than one standard deviation at the port node throughout the time horizon. We determined the effect of change in empty container volume at the port on the depot locations in the IDEC system. The deterministic analysis provided an intuitive solution - when the demand at the port was high, fewer depots opened in the region and when demand fell, more depots opened to meet the regional requirements. However, it showed that the solution was sensitive to the port demand volumes and varying future conditions resulted in large variance of inland depots required in the region. Number of depots that a depot owner may need varied widely when demand patterns changed in the region. The objective function value (total system costs) varied from \$1540M to \$1588M for depot owner 'I', \$1305M to \$1385M for owner 'II' and \$808M to \$819M for depot owner 'III'.

Long term trade predictions and projections are helpful but unfortunately they cannot be very accurate. The problem becomes critical when region and depot owners are forced to make decisions on the number and location of inland facilities to be opened in the beginning of the time horizon with imperfect information on the future demand volume. Yet, facility location decisions are long-term and need to be made early in the study horizon so that facilities can be built when they are required.

To make a decision on inland facilities and determine an optimal set of required depots (under the observed probability of the random occurrence), we analyze an 'extensive form' of the stochastic program using the three scenarios – (a) probability that demand will stay within one standard deviation, is 0.7; (b) probability that demand will fall by 15% in every time period over the horizon is 0.2 and (c) probability that the demand will grow by 15% over the time horizon is 0.1.

Before solving the two-stage program, we solve the problem using the formulated stochastic model with a constraint that all facilities must open in stage-zero. In other words, we removed the term from the model that allows opening recourse facilities in stage-one. Table 6, Columns 3 and 4 display this solution. We call it a 'single-stage analysis' and use it to determine the effectiveness of the two-stage analysis.

We next solve the problem using the two-stage stochastic program. Table 6, Columns 5-7 shows the results. All problems were solved on an Intel® Pentium® M Processor 1.60GHz, 1.56GHz processing speed, 1024MB RAM, using the CPLEX solver in GAMS IDE 2.0.35.10.

Table 6: Results of the Two-Stage Stochastic Analysis for an IDEC System

Depot Owner (1)	Scenario (Probability of Occurrence) (2)	Single stage stochastic analysis		Two-Stage Stochastic Analysis		
		All facilities open in the beginning of horizon (3)	Obj. Function (4)	Stage Zero facilities (5)	Stage One facilities (6)	Obj. Function (Expected Value) (7)
'I'	Port Demand as Predicted (0.7)	Opens 12 (#2,7,10,11,14, 18,19, 23, 26, 28, 33, 49)	$1553M	Opens 10 (#2,7,10,11, 18,19,23, 26,33, 49)	0	$1541M
	Port Demand Falls (0.2)				+4 (#14,17,28 , 45)	
	Port Demand Grows (0.1)				+3 (#14,17, 28)	
'II'	Port Demand as Predicted (0.7)	Opens 8 (#1,10,11,14, 26, 33, 45 49)	$1289M	Opens 8 (# 7,10,11,14, 18,19,26,49)	+1 (#45)	$1286M
	Port Demand Falls (0.2)				+3 (#2,33, 45)	
	Port Demand Grows (0.1)				+2 (#2,33)	
'III'	Port Demand as Predicted (0.7)	Opens 6 (# 2, 10, 11, 26, 33, 49)	$764M	Opens 7 (# 2, 7, 10, 11, 19, 26, 49)	0	$757M
	Port Demand Falls (0.2)				+2 (#18,33)	
	Port Demand Grows (0.1)				+1 (#18)	

Analysis from two-stage program showed that

- Depot owner 'I' in the region should open 10 inland facilities in stage zero. Four (4) additional facilities should be opened if demand falls in stage-one in the time horizon and 3 if demand increases at the port. Facilities open when outgoing demand at the port falls since additional depots are required to manage the increased container volume in the region. Counter-intuitively, facilities also open when the demand at the port is high and large scale global container repositioning is observed. After performing tests on this result, it was found that facilities open in this case to optimize the empty miles and transportation cost in the network and not to provide system capacity.

- Depot owner 'II' should open 8 facilities in the stage-zero. Later in stage-one, it should open 3 additional facilities if outgoing-demand falls and 2 depots if the outgoing-demand increases, as a recourse action.
- Depot owner 'III' should open 7 facilities in stage zero. In stage-one, it should open 2 facilities if outgoing-demand falls and 1 if the outgoing-demand increases.
- A two-stage approach yields lower expected system costs than 'single-stage-stochastic' or deterministic models.
- The two-stage program gives the advantage of opening dominant facilities in the beginning of the time horizon when relative cost of opening facilities is lower and later respond to the scenario by opening only additional facilities required in the time horizon.

4.5.4 Estimating the Robustness of the Two-stage Stochastic Model

Using the two-stage-stochastic-program-with-recourse model, we next investigated the impact of varying probability of demand on the optimal solution. We searched the probability space by varying the probability of occurrence. We examined the impact of varying probabilities under different scenarios to determine the solutions. Four test-cases were considered: Case 1 – scenario (S1) that is currently medium probable in the case study becomes most dominant with highest probability of occurrence; Case 2 - the scenario with least probability (S2) gains highest probability, Case 3 - the scenario (S3) that has highest probability remains dominant, and Case 4 - the three scenarios become equally likely. Table 7 shows the results. Column II shows the depot owner, column III gives the probability of occurrence considered for each of the three scenarios, column IV provides results from single-stage analysis, column V presents results from two-stage analysis and column VI finally states the difference in the expected system costs between the single-stage and two-stage analysis. Rows 1-9 display expected objective function values for Case 1. Rows 10-18 are the results for Case 2, and rows 19-27 show the results for Case 3. Rows 28-30 are the solution for Case 4.

Table 7: Estimating Impact of Demand Uncertainty on IDEC System

Row #	Depot Owner	Probability (s1, s2, s3); s1 = fall, s2 = grow, s3 = predicted	Expected Cost from One-stage Analysis (in millions of USD)	Expected Cost from Two-stage Analysis (in millions of USD)	Savings from 2-stage over 1-stage analysis
Case 1: Scenario (S1) "*Port Demand Falls from Predicted'* has the Highest Probability of Occurrence					
1	I	(0.7, 0.1, 0.2)	$1,571	$1,560	$11M
2	II		$1,305	$1,294	$11M
3	III		$774	$761	$13M
4	I	(0.6, 0.3, 0.1)	$1,569	$1,561	$8M
5	II		$1,302	$1,298	$4M
6	III		$766	$760	$6M
7	I	(0.5, 0.3, 0.2)	$1,571	$1,562	$9M
8	II		$1,303	$1,295	$8M
9	III		$763	$762	$1M
Case 2: Scenario (S2) "*Port Demand Grows from Predicted'* has the Highest Probability of Occurrence					
10	I	(0.1, 0.7, 0.2)	$1,554	$1,541	$13M
11	II		$1,279	$1,275	$4M
12	III		$761	$752	$9M
13	I	(0.1, 0.6, 0.3)	$1,553	$1,542	$11M
14	II		$1,291	$1,277	$14M
15	III		$760	$750	$10M
16	I	(0.2, 0.5, 0.3)	$1,551	$1,542	$9M
17	II		$1,281	$1,280	$1M

Row #	Depot Owner	Probability (s1, s2, s3); s1 = fall, s2 = grow, s3 = predicted	Expected Cost from One-stage Analysis (in millions of USD)	Expected Cost from Two-stage Analysis (in millions of USD)	Savings from 2-stage over 1-stage analysis
18	III		$761	$755	$6M
Case 3: Scenario (S3) "*Port Demand changes as Predicted'* has the Highest Probability of Occurrence					
19	I	(0.2, 0.1, 0.7)	$1,553	$1,541	$12M
20	II		$1,289	$1,286	$3M
21	III		$764	$757	$7M
22	I	(0.3, 0.1, 0.6)	$1,556	$1,547	$9M
23	II		$1,294	$1,291	$3M
24	III		$764	$758	$6M
25	I	(0.3, 0.2, 0.5)	$1,556	$1,546	$10M
26	II		$1,296	$1,289	$7M
27	III		$763	$758	$5M
Case 4: Scenarios have Equal Probability of Occurrence					
28	I	(0.33, 0.33, 0.34)	$1,555	$1,546	$9M
29	II		$1,297	$1,289	$8M
30	III		$765	$757	$8M

Results from the analysis (Table 7) show:

- Significant savings from the two-stage program when compared to the single-stage analysis for every depot owner under all test conditions, while providing with the flexibility to open most-required facilities in the region before the beginning of the time horizon at lower costs based on an anticipated set of future scenarios and later adapt to the occurring scenario by opening only additional recourse facilities in the horizon. The single-stage model on the other hand, opens all facilities anticipated to be useful in the time horizon in the beginning of the horizon and makes any recourse action infeasible. Therefore between the two approaches, the two-stage planning provides an economical and effective strategic solution to the problem, yielding lower expected system costs than single-stage model.

- In Case 1, when the probability of occurrence for scenario 'S1' is most likely, the expected system costs are the highest. In scenario 'S1', the demand for empty containers at the port falls from the predicted volume and therefore a large number of empty containers are stored in the region. To meet the increased regional storage demand for empty containers and optimize the network, the model opens a higher number of depot facilities in the region. This increase in number of depot facilities increases the expected system costs for the case. The model recommends opening on average 18 facilities (stage zero + stage one) for depot owner I, 13 for owner II and 11 for owner III, when scenario 'S1' is highly likely to occur.

- Lower system costs are realized when the probability of occurrence for scenario 'S2' (Case 2) is maximum or the scenario 'S3' (Case 3) becomes most likely.
    - In Case 2, the empty container demand at the port grows from the predicted volume. This translates into a large volume of containers being globally repositioned empty from the region. The large-scale repositioning of empties from the port increases empty vehicles miles travelled to the port in the region. To optimize the network under Case 2, the two-stage model recommends opening on an average 17 facilities for depot owner I, 12 for owner II and 11 for owner III.
    - In Case 3, when scenario 'S3' (demand for empty containers at the port remains as predicted) becomes most likely to occur in the time horizon, expected system costs are found intermediately between Case I and Case II. On an average 17 facilities open for depot owner I, 13 for owner II and 10 for owner III. The model

minimizes the costs incurred in repositioning predicted volume of empties in the region in this case while meeting the regional storage requirements.

- Small variation in the solution within a given case (when a given scenario 's' remains relatively dominant). Analysis from Table 7 showed no significant variation in the expected system costs and the number of facilities opening under a given case. Example, rows 1-9 in Table 7 show very low variation in the expected system costs for the depot owners among their three test conditions. Under Case 1, expected system costs for depot owner I are comparable in rows 1, 4 and 7; rows 2, 6 and 8 for depot owner II and rows 3, 7 and 9 for owner III.

- Least objective function values in a given scenario (scenario with clear dominance of occurrence) under a given case. For example, in Case 1, least objective function values are exhibited by rows 1-3 among rows 1-9. In Case 2, rows 10-12 display least objective function value in most cases among rows 13-18; and under Case 3, rows 19-21 are found to have the least system costs among rows 19-27.

4.5.5 Testing Model Adaptability

We next investigate a scenario under which decision on stage-zero facilities is taken and facilities are built, but when stage-one is reached, the probability of occurrence for the future scenarios changes completely. To illustrate an example, consider yr. 2008 as the time when it is predicted that (S1:S2:S3) = (0.2, 0.1, 0.7) is most likely to occur in the study horizon. The region builds stage-zero facilities based on this forecast and prediction. However when yr. 2010 is reached, it is observed that the probability of the three scenarios is changed completely; instead of (S1:S2:S3) = (0.2, 0.1, 0.7), the probabilities are most likely (S1:S2:S3) = (0.7, 0.2, 0.1).

We aim to analyze the adaptability of the two-stage model in such a situation and determine the usefulness of the two-stage planning and building process under such conditions. Table 8 illustrates the test-cases analyzed and results obtained. Column 3 shows the facilities that opened in stage-zero when future probabilities were (0.2, 0.1, 0.7). Column (4), (5) show the respective stage-one facilities. Column (6) and (7) shows the number and locations of facilities when probabilities of future scenarios changed. Stage-zero facilities remain the same in both cases.

Table 8: Estimating the Robustness of the Two-Stage Model Approach

Scenario (1)	**Depot Owner (2)**	**Stage Zero (0.2, 0.1, 0.7) (3)**	**When probability of scenario is (0.2, 0.1, 0.7)**		**When probability of scenarios change after stage-zero**	
			Earlier Stage One (4)	Earlier Objective Function (5)	New Stage One (6)	New Objective Function (7)
Occurrence Probability for (S1:S2:S3) becomes (0.7, 0.1, 0.2)	I	Opens 10 (#2,7,10,11, 18,19,23, 26,33, 49)	S1 = 0; S2 = 14,17,28,45; S3 = 14,17,28	$1541M	S1 = 14,17,28,45; S2 = 14,17,45; S3 = 14,17,28	$1592M
	II	Opens 8 (# 7,10,11, 14,18,19,26,49)	S1 = 45; S2 = 2,33,45; S3 = 2,33	$1286M	S1=2,33,45; S2=2; S3=45	$1306M
	III	Opens 7 (# 2, 7, 10, 11, 19, 26, 49)	S1 = 0; S2 = 18,33; S3 = 18	$757M	S1=18,33; S2=18,35; S3=18,35	$770M
Occurrence Probability for (S1:S2:S3) becomes (0.1, 0.7, 0.2)	I	Opens 10 (#2,7,10,11, 18,19,23, 26,33, 49)	S1 = 0; S2 = 14,17,28,45; S3 = 14,17,28	$1541M	S1=14,17,28,29,45; S2 = 14,17,28; S3=14,17,28	$1551M
	II	Opens 8 (# 7,10,11, 14,18,19,26,49)	S1 = 45; S2 = 2,33,45; S3 = 2,33	$1286M	S1 = 2,27,33,45; S2 = 2,33; S3 = 2,33	$1290M
	III	Opens 7 (# 2, 7, 10, 11, 19, 26, 49)	S1 = 0; S2 = 18,33; S3 = 18	$757M	S1 = 18,33; S2 = 18,35; S3 = 18,35	$763M

Results from Table 8 showed that:

- The two-stage model is effective and can economically adapt to the requirements of the unpredictable future scenarios.

- With only a small increase in the system costs over the time horizon, the future uncertainties are incorporated in the case study. Since only a few and most dominant facilities were built in stage-zero, the newly required infrastructure could easily be built upon stage-zero facilities. It is found that if (S1, S2, S3) = (0.7, 0.1, 0.2) had been known before the beginning of the study horizon, the expected system costs for depot owner I would have been $1560M (Table 8, Row 1). However, since the scenario became visible after stage-zero decision was already made (based on the earlier predictions and forecasts; S1, S2, S3 = 0.2, 0.1, 0.7), the expected system costs for owner I increased to $1592M, i.e. by 32M.

- If the condition where probability of occurrence for the three scenarios had remained as was predicted (S1, S2, S3 = 0.2, 0.1, 0.7), the expected objective function for depot owner I was $1541M. However, with the two completely new and shifted cases, the expected costs increased to $1592M and $1551M respectively under the two cases.

- A two-stage-stochastic program with recourse minimized the risk involved in investing and building depot facilities when uncertainty exists in the model parameters.

4.5.6 Discussion and Conclusion

The stochastic modeling approach presented in this chapter determines an initial set of depots to be opened in the beginning of the time horizon. These are the facilities with the highest probability of remaining optimal under all possible realizations of the future demand patterns. In addition, the model identifies a recourse action once future uncertainty is resolved.

The two-stage analysis gives the advantage of opening the dominant facilities earlier in the time horizon when fixed costs are lower and later enables to respond to the probable scenario by opening only additional recourse facilities when the future is less ambiguous. The approach minimizes total expected system costs in opening new inland depots in the region and repositioning empty containers in the network in the time horizon.

The two-stage stochastic modeling approach helps in lowering the risk of investment made in building the facilities. It helps in 'buying-in' the stakeholder groups to the concept and increase their willingness to undertake and evaluate the new proposed system. The two-stage analysis shows significant savings over the solutions obtained from a deterministic or a single-stage model.

In the next chapter, a heuristic approach is developed and presented to solve large-scale MIP-IDEC problems.

5 HEURISTIC SOLUTION APPROACH TO SOLVE LARGE IDEC-MIP PROBLEMS

5.1 Background

To test the feasibility and viability of the proposed system in port regions, the model was applied to the port region of New York/New Jersey. Four major states – New York, New Jersey, Connecticut and Pennsylvania were considered. Based on the data obtained from the regional port authority, our network constituted of 3,000+ import customer nodes (blue dots), 800+ export customer nodes (green dots), 6 existing depot facilities that are close to the port (red pointers), 53 potential inland depot sites (green circles) and 1 port terminal (red pointer) in the region. A ten-year time horizon (yr. 2010 to yr. 2020) was taken. Demand-supply volumes at the port and customer nodes were studied on a quarterly basis (40 quarterly time periods in 10-yr. horizon).

To determine optimal location of empty container depots in such large dimensional problem was almost prohibitive due to the involved computational time and cost in it. To initially study the feasibility of the proposed concept, we aggregated the customer locations to form customer clusters in the region. By reducing the number of nodes, we reduced the number of parameters and variables in the problem, which helped in solving it in an affordable time and cost. However, after proving the effectiveness of the proposed concept, we began to disaggregate the customer clusters to study the system effectiveness at a micro-scale. Disaggregating the customer clusters increased the problem dimension and made it difficult to solve.

This chapter presents a solution approach to solve large-dimensional facility location problems based on the randomized rounding search algorithm. By relaxing the integrality constraint, the algorithm converts a solution of a relaxed problem into an approximate solution to the original problem.

5.2 Solving Large-Scale Location Problems

Several algorithms have been devised to solve large facility location and location-allocation problems. In the context of locating distribution facilities and routing of vehicles from the facilities to the customers in a distribution system, a two-phase Tabu search methodology is found to be effective [55, 59]. The 'hub location' problem in transportation and telecommunication systems formulated as an uncapacitated multiple allocation problem used improved integer programming to reach the optimality [58]. Local search algorithm using the Filter and Fan method is proposed for solving large uncapacitated facility location problems [60]. The performance of generic local search, Tabu Search, and Complete Local search with Memory (CLM) on the uncapacitated facility location problem are studied and recommended for generating high quality solutions for large instances of uncapacitated facility location problems [61]. Various traditional and new search methods, such as neighborhood search, Tabu search, simulated annealing, an evolutionary algorithm and an ant-colony optimization algorithm have been compared and efficiency is examined for different search strategies in solving the location–allocation problems [83]. Transportation network design, location of facilities, definition of operating plans and complex location problems have been studied and best logistics structure for the land distribution and transportation component are provided. It is determined that using methods such as the branch-and-bound algorithm, dual ascent methods and Tabu search procedures are effective in solving such problems [84].

Local Search (LS) algorithms have been widely applied and most commonly used. Tabu search heuristic that explores the solution space by moving from a solution to its best neighbor and allows the search to move out of the local optima and explore other regions of the solution space has also seen wide application. However, both the approaches have their own set of limitations. The local search algorithm stops as soon as it encounters a local optimum with respect to the moves it considers, therefore the quality of the solution obtained and computing times are highly dependent upon the accuracy of the set of moves considered at every iteration of the heuristic. Tabu search on the other hand enhances the performance of a local search method by using memory structures, but due to the storage limitation, it is usually able to store only a fixed and fairly limited quantity of information. Additionally, when several possibilities for specific information are to be recorded, it becomes expensive to check the list.

In this chapter, the randomized rounding approximation algorithm is used to solve the empty container depot location problem. We build on the randomized rounding algorithm. It has easy and familiar basic principals and theories, and has been established as an approach yielding best approximation known by any polynomial time algorithm for solving NP-hard problems [85]. The algorithm has been used and developed in the past for problems such as, knapsack container loading problem [86], data warehouse development [87], multistage lot sizing problem in distribution, inventory systems [88] etc. But to the best of our knowledge randomized rounding has not yet been applied for locating facilities in large maritime freight network.

5.3 Proposed Solution Approach

Randomized rounding is a probabilistic method that randomly rounds each coordinate of the solution up or down (each y-value to 0 or 1) depending on the fractional part. It relaxes the integrality constraint in the mixed-integer program and solves the problem for faster, efficient and near-optimal solutions. The results are adjusted later to achieve integral feasibility. The heuristic is simple and relies on the following basic theories [89]:

(i) if X is a random variable taking values in {0, 1}; then E[X] = Pr[X = 1],

(ii) the uniform distribution on a finite set places equal probability on each element, and

(iii) linearity of expectation

Below is the developed heuristic:

<u>Step 1:</u> Solve the problem as a L.P. and get the values for the function 'y_i' (y denotes if the depot facility 'i' is open or not)

<u>Step 2:</u> Set the probability value p randomly (p = 0.8, 0.85…)

<u>Step 3:</u> Multiply y by $1/p$ and define the new value as variable y'

<u>Step 4:</u> If $y' >= 1$; set $y = 1$

for all other y's, keep them as decision variables.

Step 5: Set a threshold value q randomly (q = 0.5, 0.4, 0.3…)

Step 6: Compare y' with the threshold value (q).

Step 7: For all $q <= y' <= 1$, run a random number generator

7(a): If the random number x is smaller than y'; set $y = 1$ with probability = p, else set y = 0

7(b): For facilities, $y' < q$; keep them as decision variables

Step 8: Re-solve the L.P. problem with new set of y-values. Repeat steps 6, 7 and 8.

Step 9: If for $y' < q$ cannot be further assigned, decrement the threshold value 'q'. Repeat steps 6, 7 and 8.

Step 10: Record the objective function value and re-run the problem for 'n' iterations.

Step 11: Repeat the process with a new value of p.

Step 12: Select the best IP solution resulting in lowest objective function value, after searching the entire space of (p, q) from all the runs.

For ease of understanding, we illustrate below the above process in two flowcharts. Figure 9 illustrates the overall heuristic approach and Figure 10 describes the sub-process in the solution approach.

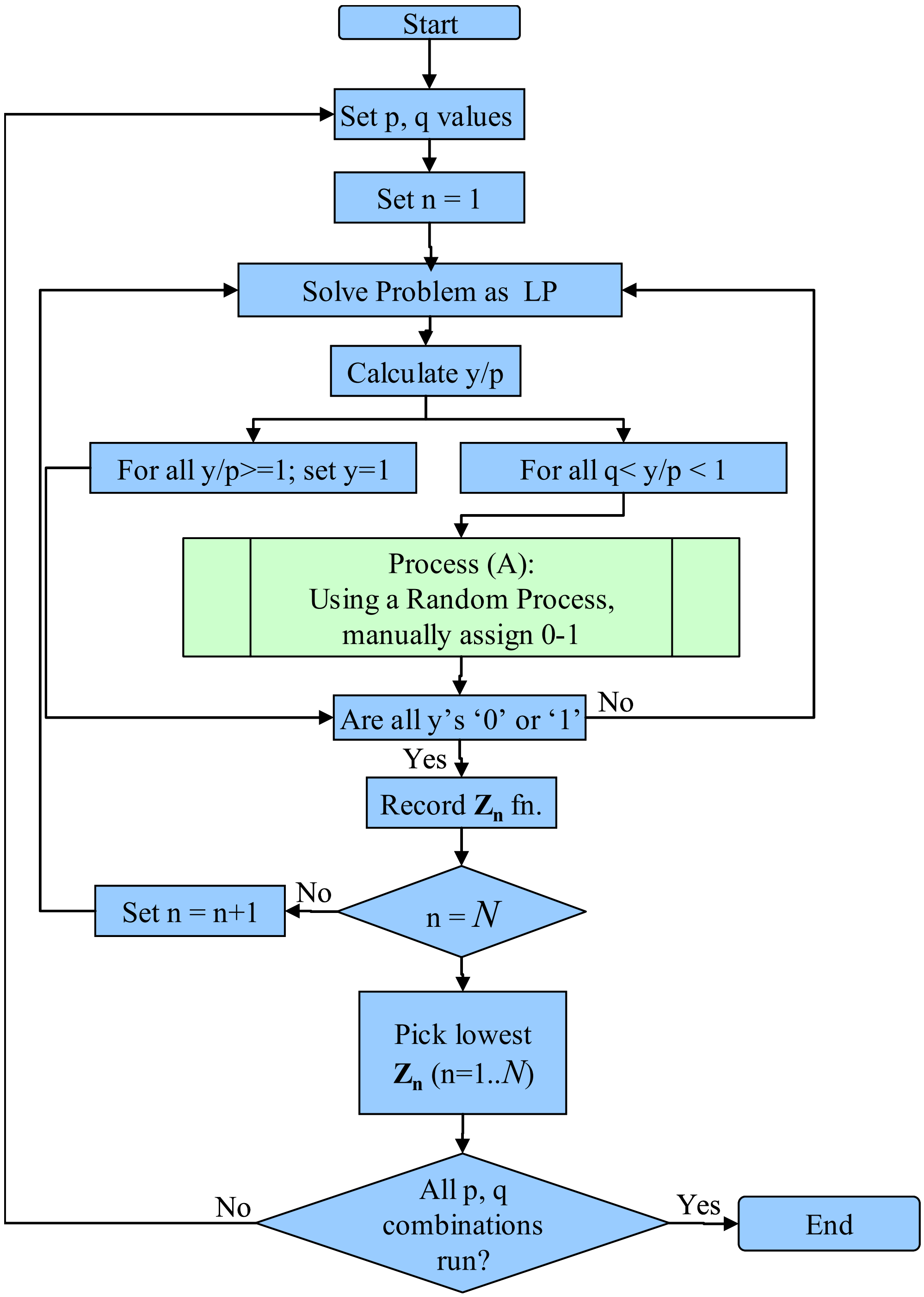


Figure 9: Randomized Rounding Heuristic: Overall Methodology

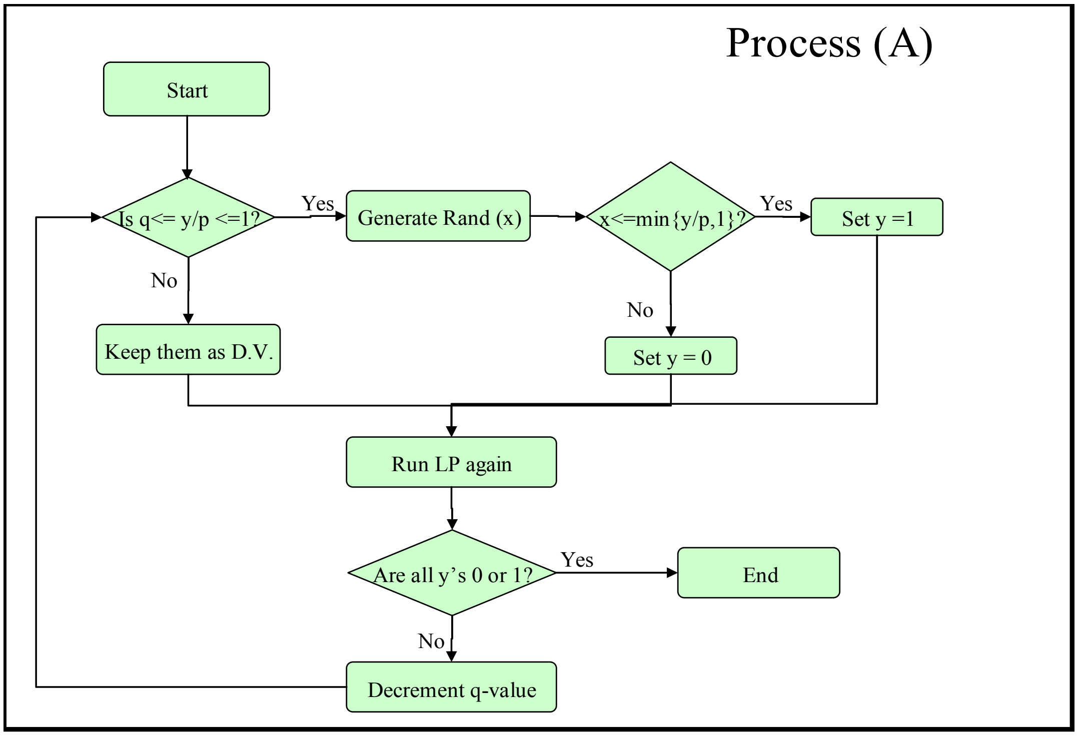


Figure 10: Randomized Rounding: Process 'A'

5.4 Implementation and Numerical Results

To analyze the performance of the proposed heuristic, we apply the algorithm to the port region of New York/New Jersey (PONYNJ) network described in previous sections.

In the previous sections, import and export business locations were clustered into 26 major customer clusters in the region, and the resulting mixed integer problems were solved to optimality. The time and effort to solve a mixed-integer program for a problem this dimension was affordable. However, when the number of customer clusters was increased to further evaluate the effectiveness of the IDEC system, the problem became computationally very difficult and almost prohibitive to solve.

We created five datasets with 100, 150, 200, 250 and 300 customer clusters in the region as test problem sets to evaluate the heuristic performance. We did not consider problems greater than 300 customer clusters since the computational cost of solving them was exorbitant and comparison with exact solution was not possible. We first solved the mixed-integer problems to optimality for all the above datasets, even when the computational cost was high for the problem sets. Next, we solved the problems using the heuristic approach.

To initiate the algorithm, we used p-value (probability-value) equal to 0.8 and q-value (threshold value) equal to 0.5. The initial seed values were critical to the quality of the solution and the computational time. To determine an appropriate seed value, we searched the space of (p, q) values and analyzed the objective function value with respect to each seed value. Results showed large variation in the objective function values. After solving a set of problems with different seed values, we found that lowest objective function values were observed when p was set equal to 0.8 and q-value was initiated at 0.5 and then decrementing at each stage of the heuristic. The 'q-value' (threshold) decrements in each run of the iteration when no more facilities remain in the search region (Step 9 in the algorithm). Decrementing the q-value, increases the search region and allows to check and open facilities required to handle expected volume in the time horizon. Figure 11 shows the variance in the objective function value with changing p-value.

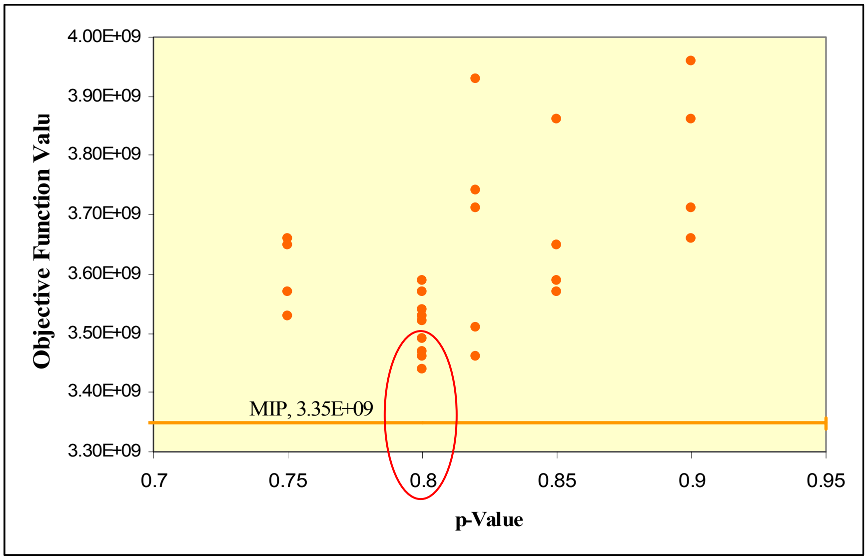


Figure 11: Observed Variation in Objective Function Value by varying p-value

The heuristic approach first searches the space of the most probable facilities (appearing with higher probability of opening) in the time horizon. Once facilities are opened from this set, it next searches for facilities with next higher probability to minimize the objective-function value, while meeting all model constraints.

5.5 Testing the Effectiveness of the Proposed Heuristic

Using the heuristic, we solve the five problem sets created with 100, 150, 200, 250 and 300 customer clusters, multiple times and record the solutions obtained. We ran the heuristic multiple times to minimize any effect of the random number generator on the solution. We note the computational time as well as the time the heuristic took to solve the problem each time. Table 9 below shows the results obtained. Next, we compared the objective function value and the computational time from the heuristic to the MIP solutions. (Note: bolded heuristic solutions in Table 9 are min(heuristic) values).

Minimum cost solution obtained after multiple runs of the heuristic approach were considered as the heuristic solution to original problem.

Table 9: Performance of the Proposed Heuristic Approach

Group	Problem	Objective Function Value	Computational Time
Group A; Problem with 100 total customer clusters in the region	MIP	3.47E+09	24 minutes
	LP	3.41E+09	3 minutes
	Heuristic: z1	3.52E+09	13 minutes per run
	z2	3.51E+09	
	z3	**3.48E+09**	
	z4	3.52E+09	
	z5	3.50E+09	
	z6	3.49E+09	
	z7	3.51E+09	
	z8	3.54E+09	
	z9	3.49E+09	
	z10	3.51E+09	
Group B; Problem with 150 total customer clusters in the region	MIP	3.38E+09	42 minutes
	LP	3.31E+09	4 minutes
	Heuristic: z1	3.44E+09	13 minutes per run
	z2	**3.39E+09**	
	z3	3.42E+09	
	z4	3.41E+09	
	z5	3.45E+09	
	z6	3.42E+09	
	z7	3.43E+09	
	z8	3.41E+09	
	z9	3.44E+09	
	z10	3.42E+09	
Group C; Problem with 200 total customer clusters in the region	MIP	3.31E+09	40 minutes
	LP	3.24E+09	4 minutes
	Heuristic: z1	3.35E+09	14 minutes per run
	z2	3.44E+09	
	z3	**3.33E+09**	
	z4	3.38E+09	
	z5	3.42E+09	
	z6	3.39E+09	
	z7	3.41E+09	
	z8	3.40E+09	

Group	Problem	Objective Function Value	Computational Time
	z9	3.42E+09	
	z10	3.40E+09	
Group D; Problem with 250 total customer clusters in the region	MIP	3.21E+09	62 minutes
	LP	3.15E+09	4 minutes
	Heuristic: z1	3.34E+09	13 minutes per run
	z2	3.32E+09	
	z3	3.34E+09	
	z4	3.30E+09	
	z5	3.36E+09	
	z6	3.32E+09	
	z7	**3.31E+09**	
	z8	3.34E+09	
	z9	3.32E+09	
	z10	3.35E+09	
Group E; Problem with 300 total customer clusters in the region	MIP	3.35E+09	97 minutes
	LP	3.29E+09	5 minutes
	Heuristic: z1	**3.42E+09**	14 minutes per run
	z2	3.42E+09	
	z3	3.50E+09	
	z4	3.47E+09	
	z5	3.42E+09	
	z6	3.52E+09	
	z7	3.44E+09	
	z8	3.49E+09	
	z9	3.51E+09	
	z10	3.48E+09	

Based on the results obtained, we determine the heuristic performance for (1) quality of the solution and (2) its effectiveness in minimizing the computational time. Table 10 presents the LP, MIP and min(heuristic) solutions for the five problem datasets and computes the distance between each of them to determine the quality of the heuristic solution.

Table 10: Observed Distances Between the LP, MIP and Min(Heuristic) Solutions

	LP	MIP	Heur_Min	Dist (LP,MIP)	Dist (MIP,Heur)	Dist (LP, Heur)
Group A:100	3.41E+09	3.47E+09	3.48E+09	1.760%	0.288%	2.053%
Group B:150	3.31E+09	3.38E+09	3.39E+09	2.115%	0.296%	2.417%
Group C:200	3.24E+09	3.31E+09	3.33E+09	2.160%	0.604%	2.778%
Group D:250	3.15E+09	3.21E+09	3.31E+09	1.905%	3.115%	4.762%
Group E:300	3.29E+09	3.35E+09	3.42E+09	1.824%	2.090%	3.951%

Results show that the heuristic approach imparts solution close to optimality and the maximum distance between an optimal solution and heuristic is 3.11%, which is fairly good and acceptable. Figure 12 shows the distance between the LP, MIP and the heuristic solution. Figure 13 highlights the reduction in computational time when solved by the proposed heuristic.

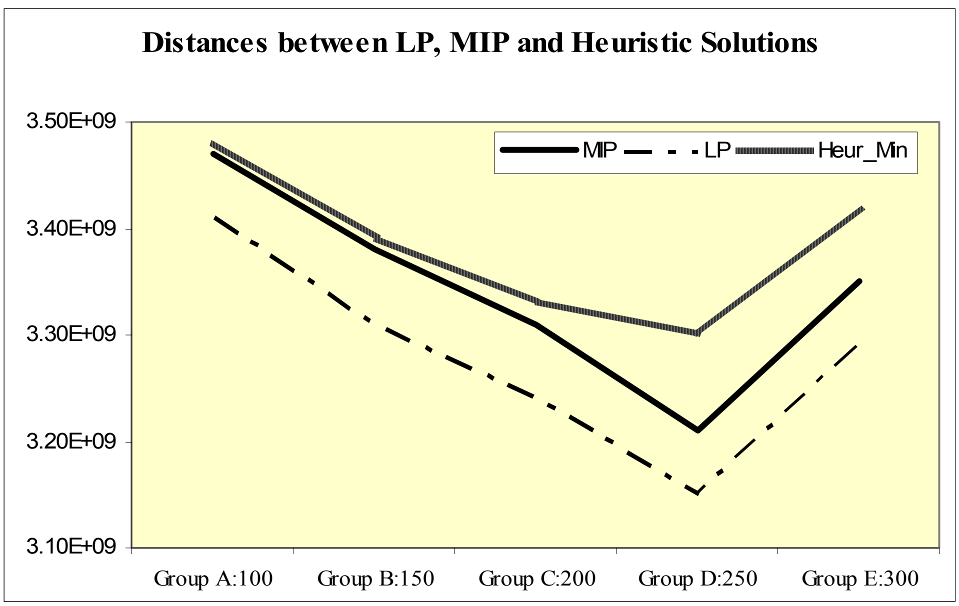


Figure 12: Distance between MIP and Heuristic Solutions

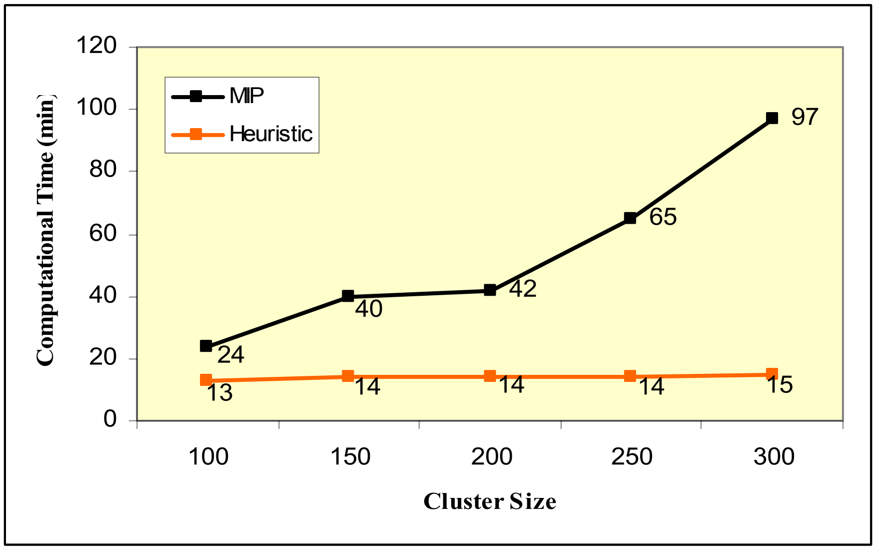


Figure 13: Computational Time vs. Problem Size

5.5.1 Testing Heuristic Performance for the problem's 'slack' value

Slack is defined as the amount of additional delay that the problem can incur before its benefit falls below some yield threshold. To test the heuristic performance for the problem's slack value, we created a scenario of demand-supply patterns where demand-supply volumes at all network nodes were reduced to 20% of the original. We create this problem to test the heuristic performance under tedious optimization conditions. By reducing the demand volumes at each node, we build a case where no facility location remains dominant and it become tedious for the model to determine an optimal set of locations in the region. It makes the optimization process lengthy and difficult. We used the problem with 200 clusters for performing this test.

When the problem was solved as a mixed-integer program, it took 1140 minutes for the machine to solve the problem. Objective function value was obtained as 9.515E+08. However, when the heuristic was applied to solve the problem, it was solved in 13 minutes and gave 9.58E+08 as the minimum objective-function value (heuristic solution). The heuristic performed within 0.6% of the optimal solution and took only a fraction (1.2%) of the time to solve. To statistically test the performance of the heuristic, we next carried-out a hypothesis testing using the t-test.

5.5.2 Statistical Testing

We considered our null hypothesis (Ho) as: There exists no significant difference between the mean of the optimal solution and the heuristic solution, and

Alternate Hypothesis (H_1) that: The means of two groups are statistically different from each other.

$$\text{t-value} = \frac{\overline{X}_a - \overline{X}_b}{SE(\overline{X}_a - \overline{X}_b)}$$

We used the optimal and min(heuristic) solutions from the five datasets to test the hypothesis. We found t-value = 0.63 and t-critical $_{\alpha=0.05, d.f.=8}$ = 2.306.

We found the t-value smaller than the t-significance, which implied to accept our null hypothesis. The testing concluded that the difference between the means for the two groups is statistically not different.

Solving very large problems

After concluding that the developed heuristic performs well and imparts solution close to optimality, we employed the approach to solve a problem with 500 customer clusters. Due to the large costs involved in optimally solving the problem with 500 clusters (1.2M rows, 1.17M columns and 6.7M non-zero variables), we could not solve the problem as MIP.

We relaxed the integrality constraint and solved the problem using the developed heuristic approach. The first LP solution to the problem yielded the lower bound on the objective function value. Next, we ran the algorithm and recorded the heuristic solution. We repeated the exercise a number of times and then finally took the min(heuristic) value from all different runs. By considering the distance between the Heuristic and the LP solution and the Heuristic and the MIP solution from Table 10, we bounded the objective function value for the problem with 500 clusters.

The problem took 7.4 minutes to solve as a LP, and yielded 2.68E+09 as the lower bound on the objective-function value. The heuristic took 16 hours to solve (where an MIP solution was not possible to be solved using the same machine) and gave 2.79E+09 as the upper bound (min-heuristic) on the solution. We determined from our analysis that the optimal solution for this problem should lie in the range of (+1.95% than LP, -1.2% than min(heuristic)), i.e. (2.73E+09, 2.75E+09).

5.6 Conclusion

In this chapter, a randomized-rounding search heuristic is proposed to solve large-scale facility location problems. The algorithm determines the number and location of empty container depots required in a region to minimize the total system costs incurred in regional repositioning of empty containers. Results obtained after solving a range of problems show that the heuristic performs well, imparting solutions close to optimality while maintaining the computational times at a reasonable level. The algorithm is found most effective for problems that are computationally prohibitive to solve as MIP and to optimality. Despite limitations of the results due to the underlying assumptions in the model formulation and dependency on accurate calculation of probabilities which can be a challenge, it is believed that the proposed heuristic will be a significant contribution to the literature and provide future researchers and practitioners with an effective algorithm to solve large-scale facility location problems.

In the next chapter, a multi-criteria decision making analysis is carried out to bring together the different stakeholders involved in the container movement. It is anticipated that the varied interests and perspectives of the different stakeholders will pose a challenge when implementing an IDEC system regionally.

6 A MULTI-CRITERIA DECISION MAKING FOR IMPLEMENTING A REGIONAL IDEC SYSTEM

6.1 Background and Introduction

It is often the case that concepts proven effective in theory are difficult to implement in the real world. The reason behind this is the inability of the decision maker to weigh the different interests and objectives of the involved stakeholders to successfully build and implement an effective strategy. A group does not usually have a single voice, which makes it important and necessary to combine judgments to grasp the final priorities of the group. Different groups have different opinions that need to be studied and analyzed.

Regional empty container repositioning involves shippers, ocean carriers, lessors, port terminal operators, port authorities, freight forwarders, truckers, depot owners, and the state/regional government authorities. The owners of containers are primarily ocean carriers and leasing companies. A shipper’s container arrives at a regional port terminal using the services of an ocean carrier. Terminals are typically owned by a port authority and are leased to terminal operators that handle the vessel loading/unloading operations and the temporary storage of containers in the terminal yard. Consignees directly or indirectly through ocean carriers or third parties (e.g. freight forwarders) arrange for inland transportation of the containers between the terminal and their inland facility (warehouses and distribution centers) by making suitable arrangements with the trucking companies. Depot owners privately own and operate depots where they provide repair and storage services for ocean containers and trade old containers. The empty container supply chain commences as soon as a container is unloaded at an importer's site and the empty container becomes available in the system. Figure 14 shows the various stakeholders involved at the different stages of empty container movement.

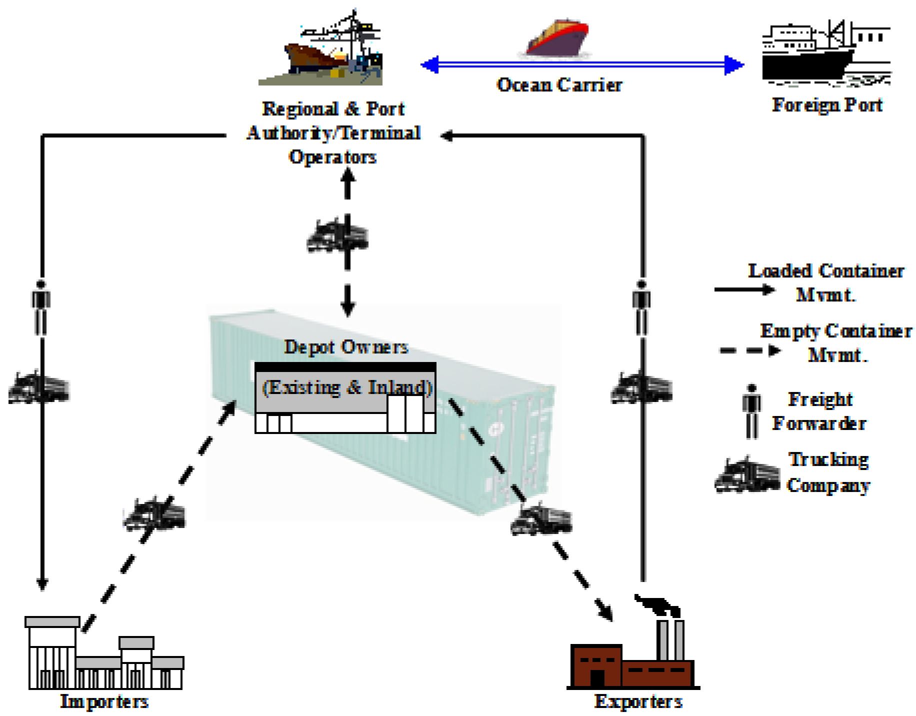


Figure 14: Maritime Stakeholders Involved in the Empty Container Movement

In this analysis, four major stakeholders are considered in the regional empty container repositioning system - the region/society, ocean carrier, depot owner, and regional import-export businesses. Establishing a new system that introduces change in the current container movement and affect involved stakeholder practices is not feasible unless consensus is reached among them and they all 'buy in' to the concept. Every stakeholder is focused on their own benefits, costs and risks from the implementation of the IDEC system. The common interest that binds the stakeholders is their gain from the savings in the cost of repositioning empty containers and the increase in their internal process efficiency and productivity if an IDEC system is implemented.

We discuss below the gains (benefits), costs and risks as perceived by different stakeholder groups. Society/region is represented by the township and county planning divisions, environmental protection and pollution control boards; depot owner community by a depot owners' consortium, ocean carriers by a group of its representatives and regional businesses by an importer-exporter syndicate.

6.2 Understanding Stakeholder Perspectives

6.2.1 Society/Region

An IDEC system can minimize the excessive empty vehicle miles travelled on regional highways and reduce the external costs (congestion, pollution, fuel consumption) associated with it. It can increase the regional productivity and economy. The proposed inland depots use abandoned, idle, and under-utilized industrial and commercial facilities, known as Brownfields, in the region, and help in land-use management. These benefits along with the creation of new jobs with the new depots are desirable to the region/society.

However, the region is concerned with the capital costs involved in building the required infrastructure to support the successful operation of an IDEC system. The social cost that it will incur due to 'spilling' of the truck traffic and environmental concerns into the inland locations from the arterial highways is worrisome.

The risks to the society/region from an IDEC system include the possible loss of maritime activity from the ocean carriers' secondary response, if the proposed system is determined as being out-of-sync with their interests and conveniences. The region is concerned with losing its regional attractiveness and competitiveness to nearby ports. There is also the risk of delay due to agitation by the local residents due to the inland location of the depots. In the past, many projects have been delayed and have struggled to proceed in view of community demands. Examples include an air cargo terminal in San Diego [90]; a center line light rail project in California [91]; construction of the Denver International Airport and a second entrance to the Ninth St. PATH station [92].

6.2.2 Ocean Carriers

Ocean carriers own a majority of the container fleet in the world. They run their shipping lines and transport the cargo. Being both the owners and carriers of containers, they are a dominant player and have an important role in the planning and development of strategies on landside container management. Most of the practices in container movement that exist today are a result of the ocean carriers' interests and objectives.

Ocean carriers incur billions of dollars every year in repositioning empty containers [93]. An IDEC system implementation will significantly reduce the regional repositioning costs incurred by them, which is the biggest gain perceived by the group from the implementation of the proposed system. However, due to (1) inertia in changing an established system, (2) fear of reduced asset visibility and control, and (3) a rare but possible risk of delayed response at the port for an empty container scheduled for global repositioning on short notice, their interest becomes limited in the proposed IDEC system. It should be noted, however, that increased involvement of ocean carriers in door-to-door instead of just port-to-port transportation would increase their interest to the proposed system.

6.2.3 Depot Owners

Depot owners have contractual agreements with the container owners (ocean carriers and lessors) and are responsible for inspecting, cleaning, repairing and storing empty containers in their facilities. In the recent past, with the increased trade volumes and the persistent trade imbalance, depot owners have experienced capacity shortfall. They have reported inventories larger than their stated depot capacities. Instead of stacking containers three to five high, they have been storing them as much as seven or eight high. With the forecasted increase in the trade volumes and land near the port becoming increasingly valuable and cost prohibitive for storing empty containers, depot owners are concerned with the additional space and capacity that would be required to sustain future demands.

An IDEC system builds new inland depots in the region to minimize the costs associated with empty container movement and provides depot owners with the additional space that would be required. The increased depot capacity, throughput, and level of customer service as well as the increased depot productivity are the benefits that will be derived by the depot owners. However, the proposed system requires monetary investments for building and operating the new depots. This capital investment is of concern to the group. The risk for depot owners in building an IDEC system is the possible loss on their investment, and a negative rate of return on their money. The other risk that concerns depot owners is the possibility of failing service level agreements with ocean carriers to supply empty containers at the port when requested on short notice.

6.2.4 Regional Import-Export Businesses

Regional businesses are the supply and demand nodes in the empty container transportation network. The benefit from the IDEC system implementation to this group is in its increased flexibility, reduced distances and reduced response time with the depot facilities. Their costs may include a higher charge for the increased level of service by the depot owners. Regional importers-exporters perceive risk in the case when the proposed system results in a loss of maritime activity in the region and shifting of trade to nearby ports, which would increase their cost of trading.

Below is a summary of the benefits, costs and risks to stakeholders discussed above.

Benefits from an IDEC system implementation:

(Note: corresponding stakeholders to the chosen sub-criteria are given in parentheses)

a. 'reduction in empty mileage', *(society)*
b. 'reduction in repositioning cost', *(ocean carriers, regional businesses)*
c. 'reduction in customer waiting time/increased level of service', *(depot owner, regional businesses)*
d. 'increased depot capacity and throughput' *(depot owner)*

e. 'increased regional competitiveness', *(society, regional businesses)*

f. 'increase in regional employment', *(society)*

g. 'improved quality of life in terms of reduced pollution, traffic and congestion', *(society)*

h. 'improved regional productivity and efficiency', *(society, regional businesses)*

i. 'better landuse management in the region', *(society)*

C**osts** to an IDEC system implementation:

a. 'capital cost in building inland depots and operating them', *(depot owner)*

b. 'cost of building virtual/electronic systems', *(depot owner)*

c. 'cost of inventory management at inland locations', *(ocean carrier)*

d. 'increased truck traffic and pollution in inland locations', *(society)*

e. 'cost of developing regional connections or intermodal connections' *(society)*

Risks from an IDEC system implementation:

a. 'agitation by local residents', - in case the location of inland depots and presence of empty containers close to residential areas agitate the local residents, (*society)*

b. 'negative rate of return', - in case IDEC does not return expected benefits, *(society, depot owner)*

c. 'maritime trade loss', – in case IDEC proves incapable of satisfying ocean carrier requirements, the region may lose on trade drivers, jobs and economy. This may require businesses to trade from other port regions, increasing their cost of trading *(society, regional businesses)*

d. 'loss in regional productivity/economy', - in case of lost maritime trade in the region, the associated regional productivity and economy would also be lost, *(society, regional businesses)*

e. 'risk of delayed response at the port for empties', - in case the empty containers available at near-dock depots are insufficient for the empty container requirement at the port for global repositioning and empty containers have to be sent from inland depots, there may be a risk of delayed response, *(ocean carriers)*

6.3 Identified Strategies

We base our identification of relevant policies and measures by actively considering the aforementioned stakeholder criteria. We propose:

1. *The state or regional government share capital cost*: Since large costs are involved in building new inland depots, this strategy would encourage and increase the willingness of the depot owners for building an IDEC system.
2. *Tax incentives be provided to depot owners when operating from inland locations*: Since costs are involved in operating depots, tax incentives may provide depot owners with an incentive to operate from inland locations.
3. *Electronic data interchange (EDI) systems be built in inland depots*: Since inland depots will not be able to comply with other stakeholder requirements without electronic data interchange systems, building these would make IDEC more acceptable and attractive.
4. *Stakeholder groups be educated on IDEC system*: Since benefits from building inland depots are long term and the existing system is not visibly breaking down,

educating stakeholder groups on an IDEC system would convince stakeholders of the benefits of the system.

5. *Cooperation and collaboration be fostered among the stakeholders*: Since primarily depot owners are the ones that invest in building and operating inland depots and ocean carriers are the ones that primarily save significant costs in regional empty container repositioning, we believe that a healthy collaboration between the two groups will be very beneficial. Marrying the two groups where ocean carriers share part of their earned revenues with the depot owners will significantly help in the sustenance of the inland depot system.
6. *Intermodal connections (rail, barge) be improved in the region*: Since a short-haul rail line between inland depots and port terminals can further increase the savings in empty truck miles travelled in the region and associated system costs, this fine tuning would enable higher savings from the IDEC system implementation.
7. *Empty container storage be regulated near the port*: Since empty container piles that are stacked as high as seven or eight in the port vicinity are considered unaesthetic, a safety hazard and a waste of valuable land, introducing strict legislation to regulate empty container storage near the port (for example, stack-height limitations and limiting expansion of existing depot facilities near the port) would force empty containers out of the urban center to inland locations.
8. *Adoption of a status quo or do nothing approach*: Since it is likely that future conditions and market forces/regional regulations will eventually force the

opening of new inland depots, we consider a status quo/do nothing approach in the region.

To understand the importance and effectiveness of these strategies in IDEC implementation, we next choose an appropriate multi-criteria decision making tool to prioritize them.

6.4 Multi-Criteria Decision Making: Choosing an Appropriate Tool

There are several different approaches available for making multi-criteria decisions. Some of the most commonly known approaches are: 'multi-objective optimization', 'goal programming', 'data envelopment analysis' and 'analytic hierarchy process'. Below we briefly discuss the advantages and disadvantages of these approaches to identify an appropriate tool for our problem.

Multi-objective Optimization: Multi-objective optimization enables simultaneously optimizing two or more conflicting objectives subject to certain constraints. The problems are solved for Pareto optimality. Multi-objective problems are primarily solved using one of four methods – Aggregate Objective Function (AOF), Normal Boundary Intersection (NBI), Normal Constraint (NC) and Multi-Objective Genetic Algorithms (MOGA). In single aggregate objective functions (AOF), different objective functions are combined into one functional form and a weighted linear sum of objectives is found. The biggest challenge with using it is in determining the appropriate weights for the different objective functions, which are subjective. The approach cannot evaluate qualitative measures and prioritize their effectiveness. However, the multi-objective genetic algorithm (MOGA) provides a methodology within the multi-objective optimization that does not require the weighing process. It applies the concept of Pareto-ranking to deliver a set of solutions optimized for different combinations of the criteria, but yields a large family of solutions [94]. The NBI and NC methods are geometrical methods for obtaining the Pareto surface. However, these methods are limited in that they cannot generate Pareto solutions over the complete Pareto frontier and thus leave the analyzer with unexplored regions and an incomplete understanding of the solution space [95].

Goal Programming: Goal programming is a branch of multi-objective optimization where some or all of the objectives are treated as constraints in a multi-objective problem. By adding slack and/or surplus variables, objective functions are converted into constraints. Every measure in the formulation is assigned a goal or a target value to be achieved. The approach is simple and easy to use. However, the challenge lies here in choosing the appropriate goal value for the constraints.

Data Envelopment Analysis: Data Envelopment Analysis (DEA) is a commonly used approach for comparing groups of similar organizational units for their relative efficiencies. It assumes that if a given unit is capable of producing a specific output, then other units would be able to do the same if they were to operate efficiently. DEA is an effective approach when estimating relative efficiency of a Decision Making Unit (DMU), but it cannot be used to determine the absolute efficiency of the unit. Also, as

DEA creates separate linear programs for each DMU, large problems are generated, which become computationally intensive.

Analytic Hierarchy Process (AHP): AHP uses qualitative and quantitative approaches to solve decision problems. Qualitatively, the problem is decomposed into a hierarchy of elements and analyzed, and in the quantitative aspect, the set of attributes is prioritized to distinguish the more important alternatives from the less important ones. The AHP approach allows using logic, human intuition, experience and information to estimate relative magnitudes and compare alternatives in pairs (paired comparison). It ranks the criteria and strategies using a relative ratio scale and assigns weights to prioritize them based on the identified benefits, costs and risks for the different stakeholders [96]. The method decomposes the goal of the problem and builds a problem structure comprised of its criteria and alternatives.

To compare the above tools and determine their suitability in solving the IDEC system implementation problem, we analyzed them on five main criteria – (1) ease in converting qualitative measures into quantitative measures; (2) ease in defining weights or goal target values; (3) in-built test for judgment errors; (4) ease in understanding the methodology and cost and computational time; and (5) ease in performing actual assessment of the strategies rather than relatively measuring them to the best strategy in the problem.

Since our problem requires assigning numerical values to qualitative measures such as reduction in pollution, congestion, increased depot capacity, and landuse management, a multi-objective optimization approach or a data envelopment analysis may be tedious to work with and may also not handle the problem effectively. Determining an appropriate numerical goal or a target value for different stakeholder objectives in a goal programming approach would be challenging. The aggregate objective function (AOF) method under multi-objective optimization may lead to non-consent and discussions on the weights assigned to each individual objective function. Assessing and calculating judgmental errors in the process of assigning weights may not be easy in most approaches. For multi-objective optimizations, not many techniques are available to solve the problems and thus compromising procedures are used that many times generate suboptimal solutions [94]. The approach requires high cost solvers and is computationally expensive. Approaches such as data envelopment analysis are found ineffective in our problem context since actual assessments were required and relative efficiency or productivity was irrelevant.

A tool that facilitates visibility of the problem and helps interpret one's knowledge, feelings and experience into quantitative measures to build decisions would by far outweigh other approaches. We judge that Analytic Hierarchy Process will be useful to the regional authorities in making their decision when realizing their wish to implement an IDEC system in their region. Analytic Hierarchy Process is easy to understand and use, computationally the least expensive, very effective in converting the qualitative aspects into quantitative aspects and, finally, handles the possible judgmental errors by its in-built calibration of consistency index and consistency ratio values.

AHP has found its application in a wide range of problem areas, ranging from simple and personal to complex and capital incentive problems in academia, industry (such as marketing, political, military, social, forecasting) and government. The seminal papers by Vargas [97] explain the AHP approach and provide an overview of the application. Examples are provided that illustrates AHP application in developing and choosing strategies, where different stakeholder groups are assessed, strategies are prioritized and multi-criteria decisions are made. The fields of civil engineering [98, 99], banking [100], government planning and development [101-104], warehousing businesses [105], and medicine [106-108], where strategies need to be prioritized to help make multi-criteria decisions, are areas that commonly use AHP for their analyses.

6.5 Analytic Hierarchy Process Analysis

The problem is structured in an AHP framework and strategies are analyzed based on the different criteria of benefits, costs and risks as discussed above.

Step 1: A hierarchy is built for the problem with goal, criteria, sub-criteria and alternatives, as shown in Figure 15. The goal is to successfully implement IDEC in a region while considering the different aspects of the different stakeholder groups.

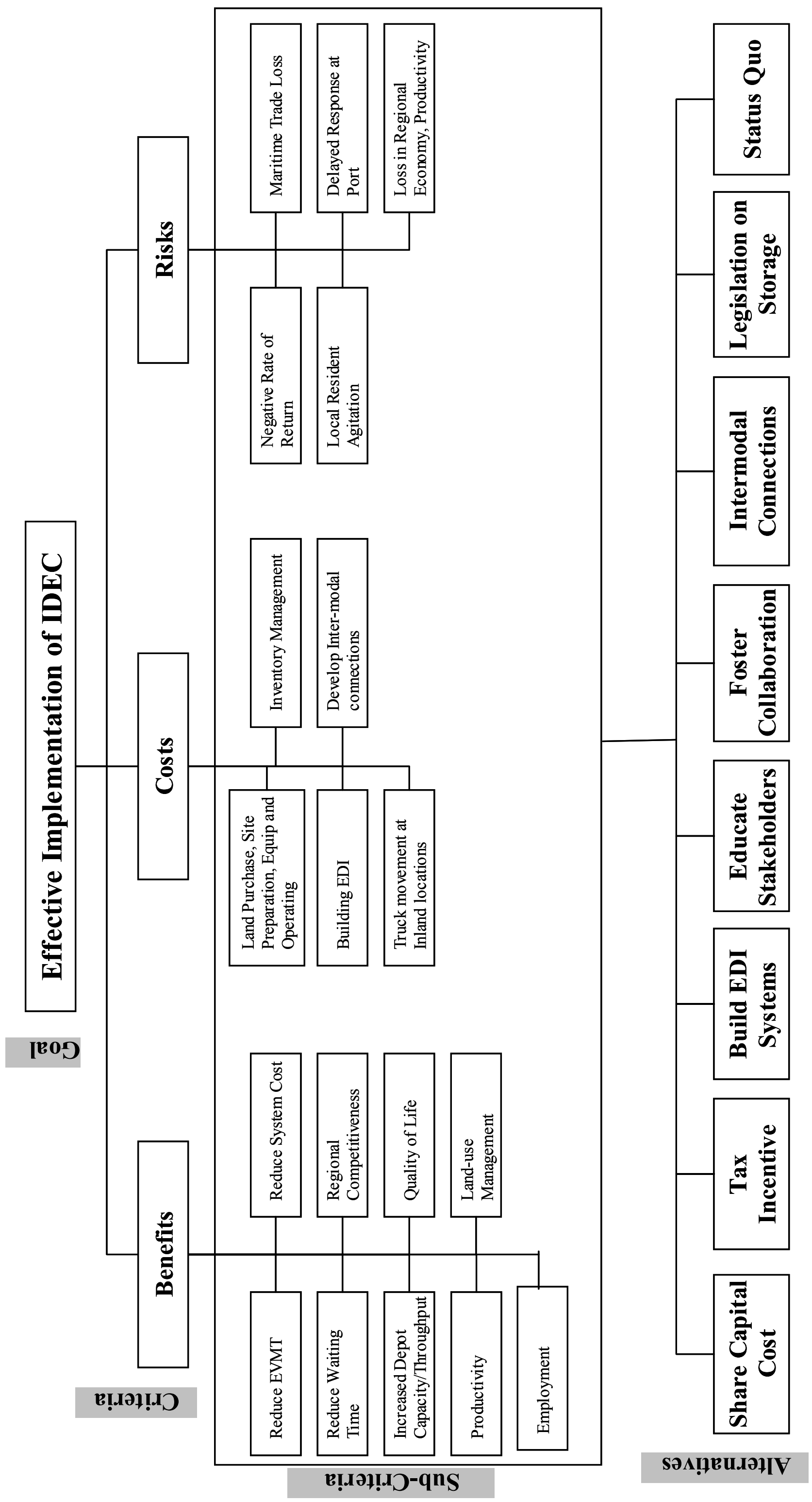


Figure 15: Problem Hierarchy for IDEC System Implementation

<u>Step 2:</u> A metascheme (underlying definition) is developed to judge the criteria and sub-criteria.

For Comparing Benefits:

- Direct benefits to the stakeholders are more important than indirect benefits to the region (e.g. reduction in empty vehicle miles traveled is more important than increased quality of life in the region).
- Trade boosting benefits are more important than societal benefits (ex. increased depot capacity from IDEC is more important than increasing jobs in the region).
- Benefit to a larger group is more important than benefit received by a small group of people (ex. reduction in repositioning cost is more important than number of jobs created in the region).
- Measurable monetary benefits are more important than un-measurable social benefits.
- Primary benefits are more important than secondary benefits (ex. reduction in repositioning cost is more important than regional landuse management).

For Comparing Costs:

- Involved capital and operating cost is a greater cost (pain) than cost of building electronic data interchange systems.
- Cost of inventory management is more important than building costs; (Ex. cost to ocean carriers in maintaining inventory across multiple facilities is a greater cost (pain) than building the facilities).

- Cost attributable to a single project is more important (painful) than cost that would benefit other regional projects as well; (Ex., cost of building inland depots is considered a greater cost (pain) than building regional infrastructural (intermodal facilities) costs).

For Comparing Risks:

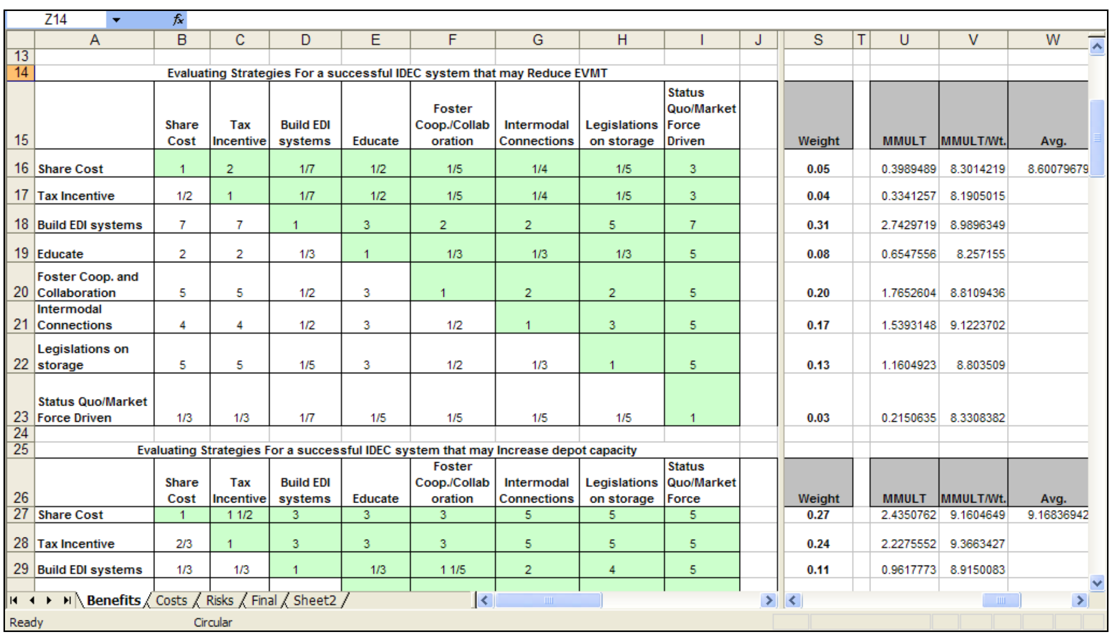
- Issues that may pose barriers to an IDEC implementation are a higher risk than monetary risks. (Ex. society agitation is identified as the biggest risk)
- Issues that may affect the region in long-term are a higher risk than short-term issues. (Ex. reduced regional competitiveness is riskier than a shorter term negative rate-of-return)
- Stakeholder risks are a higher risk than monetary risks (ex. delayed response to ocean carriers is a more important risk than any monetary risk region would incur).
- Monetary risks are a higher risk than environmental risks, given the level of environmental risk is not worse than present (ex. negative rate of return on the investments is a more important risk than pollution at inland locations because without IDEC and in the future the region as a whole would experience similar environmental concerns).

Step 3: Weights are assigned using the fundamental AHP scale where the qualitative paired comparison judgments are represented by a 1–9 scale. Table 11 below shows AHP's fundamental scale.

Table 11: Fundamental Scale of AHP

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

Weight matrices are built for analyzing the 'benefits'. A snapshot of the Excel module developed for analyzing strategies based on the perceived benefits by the stakeholders is shown in Figure 16.



Evaluating Strategies For a successful IDEC system that may Reduce EVMT

	Share Cost	Tax Incentive	Build EDI systems	Educate	Foster Coop./Collaboration	Intermodal Connections	Legislations on storage	Status Quo/Market Force Driven	Weight	MMULT	MMULT/Wt.	Avg.
Share Cost	1	2	1/7	1/2	1/5	1/4	1/5	3	0.05	0.3989489	8.3014219	8.60079679
Tax Incentive	1/2	1	1/7	1/2	1/5	1/4	1/5	3	0.04	0.3341257	8.1905015	
Build EDI systems	7	7	1	3	2	2	5	7	0.31	2.7429719	8.9896349	
Educate	2	2	1/3	1	1/3	1/3	1/3	5	0.08	0.6547556	8.257155	
Foster Coop. and Collaboration	5	5	1/2	3	1	2	2	5	0.20	1.7652604	8.8109436	
Intermodal Connections	4	4	1/2	3	1/2	1	3	5	0.17	1.5393148	9.1223702	
Legislations on storage	5	5	1/5	3	1/2	1/3	1	5	0.13	1.1604923	8.803509	
Status Quo/Market Force Driven	1/3	1/3	1/7	1/5	1/5	1/5	1/5	1	0.03	0.2150635	8.3308382	

Evaluating Strategies For a successful IDEC system that may Increase depot capacity

	Share Cost	Tax Incentive	Build EDI systems	Educate	Foster Coop./Collaboration	Intermodal Connections	Legislations on storage	Status Quo/Market Force	Weight	MMULT	MMULT/Wt.	Avg.
Share Cost	1	1 1/2	3	3	3	5	5	5	0.27	2.4350762	9.1604649	9.16836942
Tax Incentive	2/3	1	3	3	3	5	5	5	0.24	2.2275552	9.3663427	
Build EDI systems	1/3	1/3	1	1/3	1 1/5	2	4	5	0.11	0.9617773	8.9150083	

Benefits / Costs / Risks / Final / Sheet2

Ready Circular

Figure 16: Excel Module for Analyzing Strategies based on Perceived Benefits

A sample matrix comparing benefits is shown in Table 12 below. Benefits are compared based on the question, "Which alternative yields greater benefit to that criterion?" To determine judgment errors, consistency index (CI) and the consistency ratios of the comparison matrix were calculated and corrected to minimize the error.

Table 12: Weighing Benefits

	EVMT	Cost	Waiting Time	Depot Capacity	Comp etitive	Job	Quality of life	Producti-ivity	Land use
EVMT	1	1/3	5	1/5	1/3	6	4	1/3	7
Cost	3	1	6	1/3	2	7	4	4	7
Waiting Time	1/5	1/6	1	1/7	1/5	1/2	1/4	1/5	3
Increased Depot Capacity	5	3	7	1	3	4	4	3	5
Competitiveness	3	1/2	5	1/3	1	5	5	3	5
Job	1/6	1/7	2	1/4	1/5	1	1/2	1/4	3
Quality of life	¼	1/4	4	1/4	1/5	2	1	1/3	2
Productivity	3	1/4	5	1/3	1/3	4	3	1	5
Landuse	1/7	1/7	1/3	1/5	1/5	1/3	1/2	1/5	1

C.R. = 0.10

Figure 17 below summarizes the weights from the analysis where 'benefits' is the criteria.

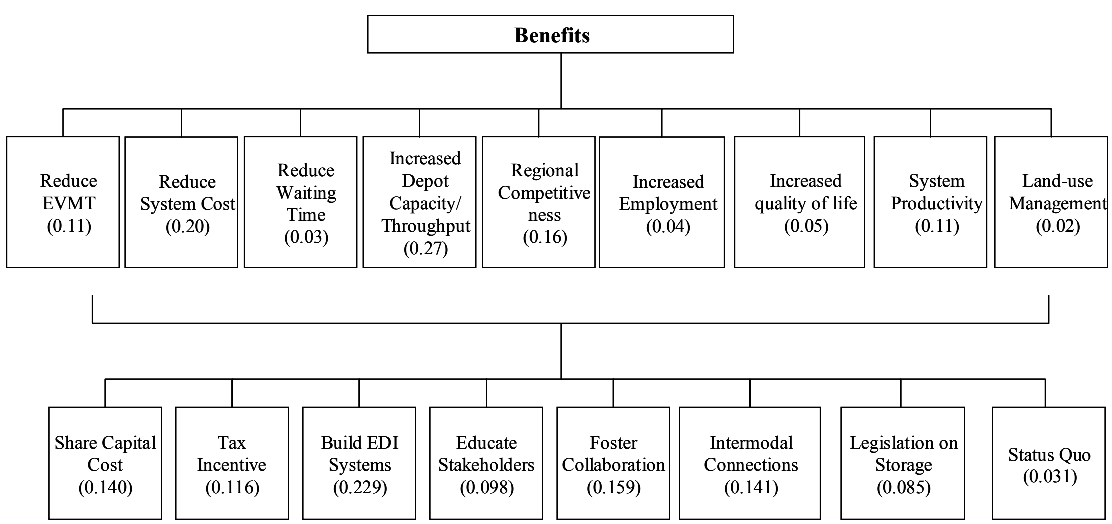


Figure 17: Weights for Benefits criteria and relative alternatives

Step 4: Weight matrices are built for analyzing the 'costs'. A sample matrix comparing costs is shown in Table 13. Identified strategies are evaluated and prioritized based on costs. Costs are compared based on the questions, "Which is a more important cost? Which alternative incurs greater cost to that criterion?"

Table 13: Weighing Costs

	Land/ Site	Equip/ Operate	Electronic systems	Increased trucks inland	Build regional connections
Purchase Land/Prep Site	1	5	3	1/7	3
Inventory Management	1/5	1	2	1/5	3
Build Electronic systems	1/3	1/2	1	1/5	1/3
Increased trucks inland	7	5	5	1	5
Build regional connections	1/3	1/3	5	1/5	1

C.R. = 0.07

Figure 18 below summarizes the weights from the analysis where 'costs' are the criteria.

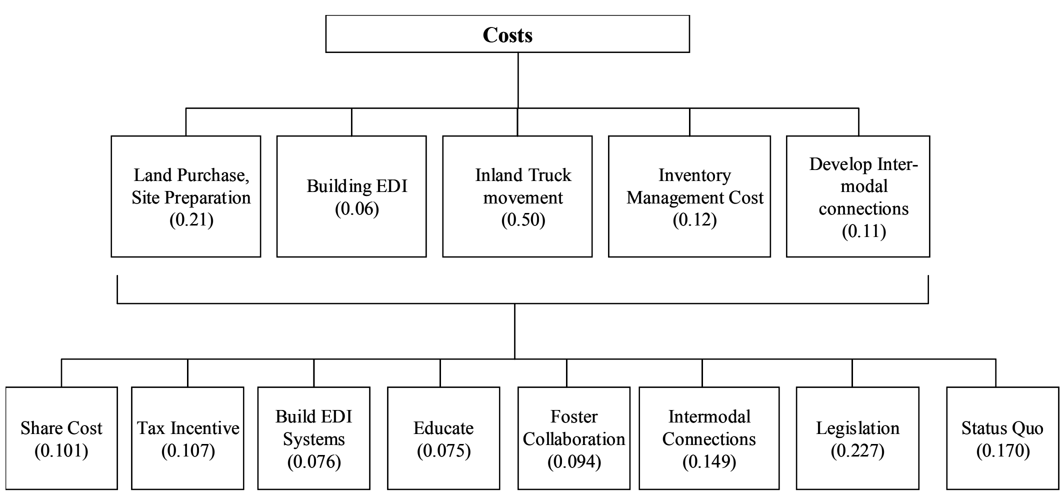


Figure 18: Weights for Cost criteria and relative alternatives

<u>Step 5:</u> Weight matrices are built for analyzing the 'risks'. A sample matrix comparing risks is shown in Table 14 below. Identified strategies are evaluated and prioritized based on risks. Risks are compared based on the question, "Which criterion is a more important (higher) risk?"

Table 14: Weighing Risks

	Neg. RR	Maritime trade loss	Resident agitation	Delayed response at Port	Eco/Prod loss
Neg. RR	1	¼	1/7	1/5	1/3
Maritime Trade Loss	4	1	1/5	1/4	2
Resident agitation	7	5	1	4	6
Delayed response at Port	5	4	¼	1	4
Eco/Prod loss	3	½	1/6	1/4	1

C.R. = 0.10

Figure 19 below summarizes the weights from the analysis where 'risks' are the criteria.

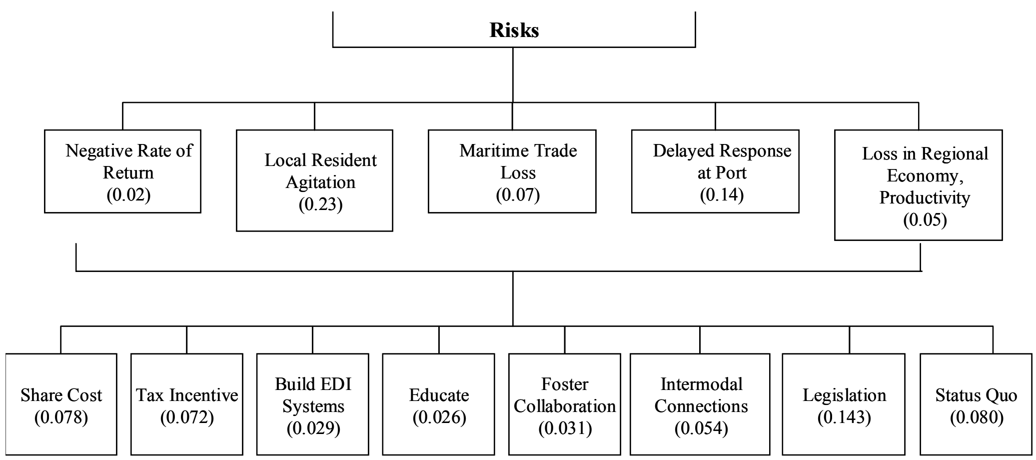


Figure 19: Weights for Risk criteria and relative alternatives

<u>Step 6:</u> To determine the relative effectiveness/ priority of the identified strategies, a B/CR (Benefit/(Cost*Risk)) ratio is calculated, as shown in Table 15.

Table 15: B/CR Ratio

	Share Cost	Tax Incentive	Build EDI systems	Educate	Foster Collaboration	Intermodal Connection	Legislation storage	Status Quo
Benefit	0.140	0.116	0.229	0.099	0.159	0.141	0.085	0.031
Cost	0.101	0.108	0.076	0.076	0.094	0.150	0.228	0.170
B/C	1.392	1.077	3.002	1.310	1.689	0.939	0.371	0.181
Risk	0.079	0.073	0.029	0.026	0.031	0.054	0.143	0.080
B/CR	**17.629**	**14.816**	**103.043**	**49.491**	**54.541**	**17.381**	**2.597**	**2.251**
Percent Weight	6.73%	5.66%	39.37%	18.91%	20.84%	6.64%	0.99%	0.86%

<u>Step 7:</u> To assist regional authorities in determining the allocation of its resources in case additional resources are obtained, a marginal benefit-cost ratio is calculated to achieve greatest marginal return from the investment. Marginal benefit-to-cost ratios are obtained by arranging the alternatives in increasing cost priority and then calculating the ratios corresponding to the smallest ratio, followed by the ratio of the differences of the successive benefits to costs $\{(b_{i+1}-b_i)/(c_{i+1}-c_i)\}$. Table 16 below shows the marginal B/C ratios.

Table 16: Marginal Ratio Analysis

	Cost	Benefit	B/C	Marginal B/C
Educate	0.0756	0.0991	**1.31**	
Build EDI systems	0.0764	0.2293	**3.00**	**169.57**
Foster Collaboration	0.0943	0.1592	**1.69**	**-3.92**
Share Cost	0.1009	0.1404	**1.39**	**-2.83**
Tax Incentive	0.1076	0.1159	**1.08**	**-3.67**
Intermodal Conn	0.1499	0.1407	**0.94**	**0.59**
Status Quo	0.1701	0.0307	**0.18**	**-5.44**
Legislation storage	0.2277	0.0845	**0.37**	**0.93**

6.6 Results and Discussion

To determine the relative effectiveness of strategies in IDEC system implementation, we analyzed three ratios – benefit/(cost*risk) (B/CR), benefit/cost (B/C) and the marginal benefit/cost (Marginal B/C) ratio. We discuss below the results based on these ratios.

Analysis from B/CR ratio revealed that building electronic data interchange systems at inland depot locations should be on the apex of the priority list for effectively and sustainably implementing an IDEC system. At first glance, this may seem counter-intuitive, as one may think that cost sharing or monetary incentives given to the stakeholders will typically be more effective in implementing such capital intensive systems. But the fact is facilitating information flow to the stakeholders is a vital component to the success of the IDEC system. Without electronic infrastructure in-place at inland locations, the proposed system will not be able to comply with 'depot direct off-hiring' services provided currently by the terminal operators and not provide the asset visibility required by the ocean carriers.

Second on priority should be the strategy that may foster cooperation and collaboration among stakeholder groups; efforts that may bring ocean carriers and depot owners together and build mutual agreements to share capital cost of building the proposed system. It is believed that since IDEC would significantly reduce the cost of empty container repositioning for ocean carriers, but at the same time require depot owners to invest and provide such facilities, marrying the two groups would significantly increase the viability of the system implementation. Based on the savings in cost of repositioning empty containers in a region and the percentage of service obtained by an ocean carrier from the inland facilities of a depot owner, ocean carriers can share their savings from the inland infrastructure. It is believed that this strategy would benefit both groups significantly and build a feasible, practical system.

B/CR analysis highlights that educating stakeholders on the proposed IDEC system and acquainting them with the benefits, costs and risks involved in establishing the system would help in providing a head-start to the system implementation. Conducting seminars, meetings and group discussions in the region where involved stakeholders could further discuss their concerns and contribution will help in speedily establishing the system.

The analysis shows that strategies such as regional incentives (capital cost sharing by a central body, providing tax deductions to the depot owners on their revenues earned from inland locations) can be effective in implementing the IDEC system; however these will be lower on the priority list. Legislation and policies restricting empty container depot expansion near the port and limiting the stack height of the containers in the depots (reduce depot capacity) can force the stakeholders to seriously evaluate the potential of inland locations and help in building and developing the inland network of depots (IDEC system), but a pro-active action would be more beneficial in the long-term. Providing regional or intermodal connections (rail or barge links) to the port from the inland depot locations would help in additional reduction of empty truck miles in the region and would make the IDEC system more attractive and appealing, but would be a fine tuning to the system, something to be considered later in the time horizon. The analysis showed that the least effective strategy would be to maintain a status quo or take a ‘do-nothing’ approach. This approach that waits for the market forces to drive the implementation of an IDEC system in the region will be the most ineffective one.

Comparative analysis from the B/C ratio revealed that building electronic systems (Internet based information portals) and supporting infrastructure in inland depots would most significantly help in establishing the system successfully. Both B/CR and B/C ratios concluded that second on priority should be the focus on fostering cooperation and collaboration among the different stakeholder groups. An effort to promote capital and operation cost sharing between the ocean carriers, and depot owners without violating anti trust laws can be an effective strategy for successfully implementing and sustaining an IDEC system in the region. However, B/C ratio elected ‘sharing capital costs by the government as the third on the priority, whereas the B/CR ratio (with nearly 19% share) revealed ‘educating stakeholder groups’ as a more effective strategy.

When strategies were analyzed using a marginal ratio analysis, we determined that a region would receive the greatest benefit and return on its additional budget by investing the money in building EDI systems and providing electronic infrastructure to the system users.

6.7 Conclusion and Recommendation

Maritime transportation is a complex industry with several stakeholders involved in the movement of marine containers. To implement a region-wide strategy that influences the movement of these containers, regional authorities need to understand the requirements, interests and objectives of the various involved stakeholders. As different stakeholders have different interests and objectives, challenges in IDEC system implementation can be anticipated. In this paper, different perspectives (benefits, costs and risks) of the involved stakeholders have been modeled and analyzed to reach a multi-criteria decision.

Analytic Hierarchy Process (AHP) was found as an effective tool for the study problem since it facilitated easy visibility of the issues and helped in interpreting our knowledge, inutition and experience into quantitative measures, while making decisions. It is recommended that future IDEC implementing groups may consider AHP as a tool-of-choice for their multi-criteria decision making; in-spite of its subjective nature of preference weighing that can sometimes lead to questions of validity and unrealistic expectations from policy decisions.

Based on this analysis, it is recommended that IDEC implementing authorities should consider strategies such as building electronic infrastructure at inland facilities, fostering cooperation and collaboration between ocean carriers and depot owners, and educating involved stakeholders on the benefits, costs and risks from an IDEC system implementation, as most effective for successfully building and establishing the proposed system. Even though, differences are observed between B/CR and B/C ratios on the third priority, more emphasis is provided to the results obtained by using the B/CR ratio, since it signifies a more dynamic relationship between the variables and takes into account the risks involved with each alternative, unlike the B/C ratio.

During this analysis, it was found that it is critical for the implementing authority to understand the system completely and know the relative importance of each stakeholder in the system. Even while it is critical to pay attention and reflect on the stakeholder concerns, the final assignment of weights and judgment should be made by the authority under unbiased conditions of any stakeholder group in the system. It is hoped that the analysis performed in this paper will function as a template for future IDEC implementation projects around the world and provide the implementing authorities with a feasible and valuable approach. IDEC system implementing authorities and the existing AHP practitioners will benefit in their future applications from the problem structure developed in this chapter and the comprehensive metascheme provided during the analysis.

In the next chapter, broader impact of the proposed IDEC system is discussed. The viability and potential advantages from the proposed system are discussed with respect to the current and future dynamics, and advancements in the maritime industry.

7 BROADER IMPACT OF IDEC SYSTEM

7.1 IDEC System beyond the Case-study Region

For this research study, the port region of New York/New Jersey has been used for the purpose of demonstration and case study analysis. However, the proposed modeling framework can be easily adapted and utilized in other port regions of North America and Western Europe where comparable growth in volume and trade imbalance is observed. In this chapter, we explain the necessity of a system such as IDEC in those regions and provide a brief discussion on the derivable benefits and advantages from it.

We consider the major port regions of Los Angeles/Long Beach and Seattle/Tacoma on the West coast of United States, which are very different when compared to the NY/NJ region in their volume handled and their distribution pattern. Most containers that arrive in NY/NJ stay within the region, whereas more than half of the cargo that arrives in LA/LB is shipped to other parts of the country intermodally (rail or truck). Despite this difference, the underlying issue of unproductive empty miles generated within the regions and the high costs incurred in empty container repositioning persist. Southern California region in year 2000 reported that it emptied nearly 1.1 million import containers in its region, which were trucked back empty to its marine terminals and depots nearby. At the same time approximately 500,000 empty containers were trucked from the marine terminals/depots to the region's exporters [109]. For the region of Seattle/Tacoma, while we were not able to obtain published volumes of container movement for the region, we know that warehouses and distribution centers are located about 75 miles away from the port [9]. Containers travel between the regional customer locations and near-dock depots with every demand and supply generated in the region. An IDEC system in such regions would reduce the empty vehicle miles travelled in the region and the system costs in regional repositioning of empty containers.

To consider a region with a completely different set of characteristics, we next consider the mid-Western region of the United States. In this region, a large manufacturing base (high exports) is present, which make it distinctly different from the high-import NY/NJ region. An IDEC system would continue to be effective in regions such as mid-West, since the large regional export demand would enable matching of import containers with the export container requirements. Inland depots being co-located with the regional customer clusters will allow a local match instead of empty containers traveling to and from the rail yard. The balanced trade pattern would actually result in a more effective IDEC system. It should be noted that an IDEC's role would be more in providing logistical support than in serving as regional container storage facilities in such high-export regions. Since storage demand will not be as high as in higher import activity regions, inland depots would still be required to minimize the empty vehicle miles traveled and costs incurred in repositioning empties.

Based on these case studies and the analysis performed in this research, it is believed that with the anticipated increase in trade volumes and the chronic and evolving imbalance of global trade, the proposed system is a promising solution in addressing the regional empty container management problem, meriting further consideration.

7.2 IDEC to Deal with the Container Crunch Issue

In the past couple of months (April 2008 onwards) news reports are filled with the issue of empty equipment shortages for the exporters in the U.S., which is hampering US export efforts. Until recently, the focus was on returning US inbound containers to Asia as fast as possible. The majority of containers shipped westbound across the Pacific were empty, with little export cargo to fill them. Now ocean carriers and forwarders are struggling to cope with rapidly shifting trade patterns. Beginning late last year, the availability of empty containers has dropped as U.S. imports have softened. With fewer containerized shipments of imports from Asia, shipping lines have fewer empty boxes available for exporters. The imbalance worsens as U.S. exports soar. Some of the primary reasons behind the increased exports from the U.S. are [110-113]:

1. Depreciating US dollar: Since dollar has devaluated, US goods have become cheaper in the foreign market. The weak US dollar is fueling demand for US exports and making foreign-made goods more expensive. As a result, more shipping containers are leaving the US than returning. Shipping lines have started diverting their services from Asia-US to Asia-Europe, which has become more profitable. This practice is bringing fewer containers into the country.

2. Large Pork and Poultry demand: The record large U.S. pork and poultry production with relatively low domestic prices has made items in these categories attractive in the global market. Outbreaks of animal disease in some other countries have driven more international sales in these than ever before.

3. Economic recession: Since the purchasing power of consumers in the U.S. has fallen in the past few months, demand for goods has fallen proportionally, impacting the total import volume and containers in the U.S.

4. Surge in cost of transporting cargo as bulk: Since the shipping cost of bulk cargo has considerably risen; cargo from bulk is shifting to containers, resulting in shortfall of containers/lesser availability of containers. Example, higher charter rates for bulk cargo ships have resulted in increased quantities of grain being exported in containers, reducing space for other cargo.

5. Limited Vessel Capacity: Since import goods into the U.S. are generally lightweight goods (clothes, toys, and electronics), whereas exports are heavy-weight such as grains, lentils, and paper; ships are reaching their maximum weights with fewer export containers. A ship that comes in with 90 percent of the container slots fully utilized may only be able to fill 65 to 70 percent of those slots with export containers. The combination of relative reduction in import containers into the U.S., and increase in containerized exports has led to the shortfall of empty equipment.

6. High Cost of Railing Empties: Shipping empty containers to the inland locations is an expensive proposition, especially with today's rail rates being 30 to 40 percent higher than rates a few years ago. So the lines don't want to pay that cost unless they are sure that they will pick up containers that will provide enough revenue to cover their costs.

Ocean freight rates on exports are up dramatically, but they are still considerably lower than on imports in most trades, so the incentive for moving containers into the interior isn't as high as it would be if the lines could get higher-paying cargo.

However, U.S. is still importing more than it is exporting and the problem of empty equipment shortage is reported to be more severe and acute in the inland locations of the country than in port cities. Port cities are less affected by the crisis due to their still existing key role as import gateways. Analyzing this shortage of empty equipment with respect to the proposed IDEC system, it is believed that an IDEC-system in-place can help under such situations. Since IDEC recommends opening new empty container depots at inland locations closer to customer clusters, it can deal with localized accessibility and exchange of empty containers easily. Reports that say "*exports are booming, and exporters in the Midwest are facing a critical shortage of containers, but try telling that to people driving along the highway outside the marine terminals in northern New Jersey and you'll get a puzzled look. If there's such a shortage, why are there still so many empty containers stacked on top of each other?*" It clearly shows that the issue is not insufficient amount of empty containers available in the country, but the issue is inefficient distribution of the equipment. Thousands of empty containers are available in the port regions but to transport them to inland locations when demand generated is challenging and time-consuming.

Inland depots can store empty equipment and maintain a container inventory at inland locations, providing higher flexibility and accessibility to the importers and exporters for fulfilling their empty container demand-supply in a timely fashion. The surging U.S. exports can find export counterparts for the import containers with an IDEC system in place.

7.3 IDEC and Future Maritime Advancements

In this section, we discuss the feasibility and viability of the proposed IDEC system with respect to the future developments in the maritime industry. Based on the pilot projects that have recently initiated and are evaluating for the program effectiveness [114-116] include developments such as establishment of freight villages; inland ports and inland terminals. Freight villages are defined areas within which all activities relating to transport, logistics and the distribution of goods, both for national and international transit, are carried out by various operators. Inland port or terminals are specialized facilities that perform some functions traditionally carried out at a seaport. Rather than goods being loaded and unloaded at ports, shipping containers are transferred between ship and truck or ship and train. An IDEC-system co-located with such facilities would be very beneficial and effective in the region to minimize the costs and empty miles travelled in the region. Since inland depots would be close to the import-export container activity, it would be beneficial to locate them near a freight village to manage regional empty containers. A dedicated facility for repairing and storing empty containers close to such a facility can provide capacity and internal efficiency to each other’s operations.

Larger vessels with larger capacities are another advancement that is underway in the maritime industry. It is estimated that about 1,500 new ships and approximately 6.7M

TEU of containers are on order and to be delivered in the next couple of years. Several shipping lines are close ordering the first containerships of more than 8,000-TEU capacity [117]. Figure 20 below shows 'Emma Maersk', one of the largest container ships in the world with a capacity of 12,508 TEUs, owned and operated by Maersk Line.

Figure 20: Emma Maersk – One of the Largest Container Ships

With large ships and higher volume of containers arriving in port regions, it is imperative for them to start building and planning for the new generation of container ships and management of container volumes they bring with them. An inland infrastructure that is robust and adequate enough to sustain the trade will be the key to success. Inland depots will prove further beneficial and economical alternative to the existing landside empty container repositioning.

Radio Frequency Identification (RFID) has gained enormous popularity in the past decade and it has been well-adapted to meet the requirements of the maritime industry. There are many challenges associated with ocean shipping. Losses occur due to cargo theft and piracy. In addition, after 9-11, security concerns in the transportation industry have increased. New regulations and the threats of more regulations have been introduced in the process. RFID has been explored and in some cases implemented to solve these problems. An RFID tagged container in an IDEC system will further help in increasing the container owner's asset visibility at every major step in the maritime supply chain. It is believed that inland container depots will be able to provide better information for tracing and tracking the containers, making IDEC more appealing and accepting to the involved stakeholders.

Another new invention and area of research in increasing the maritime trade efficiency has been in developing safe foldable containers. Efforts are underway to construct containers that can be erected in a small time with less skilled labor and is safe to operate. Foldable containers, such as those shown in Figure 21, are designed with hinged walls to fold down when empty. They can save space and reduce the cost of moving empties. According to a collapsible container manufacturer, some of the key features of collapsible containers include: (a) increased return ratios (empty containers outbound vs. full containers inbound); (b) they are designed with folding walls that allow them to collapse to a shorter height. This allows many more containers to be shipped back with the same cubic space as setup containers and when shipped, they reduce the logistical need for land storage; and (c) straight walls of set up containers allow more cubic interior box space and maximum product per inbound container. Some issues to consider in a more detailed evaluation of this option include the savings in empty storage vs. non-collapsible container option, savings in empty container return freight cots vs. non-collapsible option, repair and durability issues of moving parts of folding walls, and time and labor costs to collapse vs. space/return freight savings.

Figure 21: Foldable Containers

Foldable containers that are present in the market today are found unsafe and time expensive in most instances of their use. Accidents have occurred in the past involving containers with non-counterbalanced ends. In one case, the ends of the container were unlocked and allowed to fall under gravity. In another case, the ends had not been locked in the upright position and when the last side gate was dismantled the unsupported end frame toppled. However, if the technology develops and containers come into the market as are expected soon to arrive [118], IDEC may not be required to fulfill the regional storage capacities in regions with higher import activity, but nevertheless, its significance and use will not be dampened since it will still remain to act as logistical support centers to optimize the empty vehicle miles traveled in the region.

In the next and the last chapter, a few pointers on the future research direction analyzing an IDEC system are provided.

8 FUTURE RESEARCH DIRECTION

Empty container fleet management is a critical issue in the maritime industry. Several efforts have been made in the past, both academically and by practitioners, using quantitative and qualitative analyses to minimize the costs incurred in repositioning empty containers. In the research undertaken here, a new concept has been proposed for optimizing regional empty container moves. The feasibility and viability of the proposed system is studied and analyzed. Varied perspectives of different maritime stakeholders have been studied and possible challenges anticipated in implementing the system are discussed and attempted to solve through strategic measures. It is hoped that the proposed IDEC system will provide a novel approach to efficiently manage the empty marine container transportation network, realizing cost savings and better service, furthering the objectives of all the stakeholders. This, in and of itself, would be a significant step in bringing cooperative thinking among disparate groups of organizations/ agencies that drive the maritime network. An IDEC system has great potential in optimizing regional empty moves, improving both business profitability and social welfare concurrently.

However, the research study has an enormous scope to expand and be analyzed, given the complex and dynamic nature of the industry. Below are some of the pointers provided for future research to further build upon and explore the proposed inland depot concept:

- Inclusion of Operational Costs in the Model: Operating cost of inland depots may be added as a term in the objective function of the models developed in this study. This further detail in the model may help in estimating the effect of operational costs in strategic decision making. It is anticipated that incorporating operational costs (fixed and variable) of depots may further decrease the number of facilities opening in the time horizon, however, the total system costs may not be significantly different. Data analysis should be carried out and the above hypothesis be proved.

- Multi-objective Optimization to Model Quantitative Stakeholder Behavior: With such a model in place, sensitivity analysis could be performed for all the stakeholders associated with regional repositioning of empty containers.

- Analysis on the Impact of Future Maritime Advancements on IDEC System (RFID, foldable containers): The effectiveness of an IDEC system with future maritime advancements has been discussed in Chapter 7. However, a quantitative analysis to prove the discussion will help in analyzing and establishing the proposed system effectively and strategically. Some of the questions that future analyses could analyze are:
    a. How foldable containers would affect the optimal number and location of new depots in an IDEC system.
    b. How would foldable containers affect the depot building and operating costs in the model, and affect the system design.
    c. What savings would RFID tagged containers provide to the empty container repositioning system? How would they help stakeholders buy-in to the proposed IDEC concept?

- A Detailed Study of the Impact from the Factors that Affect Container Demand at the Regional Nodes: Where possible, a larger and detailed dataset on the demand-supply volumes be collected and analyzed for a study region. Using the demand volumes by fortnights or monthly, instead of quarterly volumes used in this analysis be used to observe the demand variation at the regional customer nodes. Both deterministic and stochastic analysis will improve with the larger and detailed dataset.

- Expanding and Analyzing the IDEC-concept on an Inter-regional/ National Level: In this research, an IDEC system has been proven effective at a regional level. However, future studies could expand this study region to include analysis at inter-regional levels. Using the concept of inland depot system and empty container storage locations near the import-export businesses as well as the mathematical models developed in this research, empty container repositioning will be analyzed at all levels –global, inter-regional and regional.

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10 CURRICULUM VITAE

NEHA MITTAL

Education

- Rutgers, The State University of New Jersey, New Brunswick, New Jersey
  Doctor of Philosophy, Transportation Engineering, October 2008

- Rutgers, The State University of New Jersey, New Brunswick, New Jersey
  Master of Science, Transportation Engineering, October 2004

- L.D. College of Engineering, Gujarat University, Ahmedabad, India
  Bachelor of Engineering, Civil Engineering, June 2000

Refereed Journal Publications

- Boile, M., S. Theofanis, A. Baveja, N. Mittal, "Regional Repositioning of Empty Containers: A Case for Inland Depots," Transportation Research Record – Journal of Transportation Research Board. (Forthcoming)

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