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ON EXPORT INTERMODAL TRANSPORTATION PROBLEM

ON EXPORT INTERMODAL TRANSPORTATION PROBLEM

A thesis submitted in partial
fulfillment of the requirements for the degree of
Master of Science in Computer Science

By

Supriya A Jadhav
University of Pune
Bachelor of Engineering in Computer Engineering, 2003

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ABSTRACT

This thesis investigates a logistics problem facing companies that export their products to other countries. The problem is called export intermodal transportation problem. In the export intermodal transportation problem, goods ordered by overseas customers need to be transported from production plants or warehouses of an export company to the customers destinations overseas. The transportation involves using multiple transportation modes such as trucks and rails for the inland portion and ocean liners for the overseas portion, and its objective is to have the goods moved and the cost minimized subject to various constraints. Cost can be minimized by combining orders from different customers to reduce the number of trucks, rails, or ocean containers used, and by selecting the appropriate transportation modes, routes and carriers.

This study provides a formulation of the export intermodal transport problem and proposes two approaches to solve a relaxed version of the problem, where the time constraints are ignored. The first approach divides the problem into three sub-problems: order consolidation on ocean container, ocean port and carrier selection, and inland transportation mode and carrier selection. Order consolidation on ocean container is formulated as the bin packing problem and is solved by the first-fit decreasing algorithm. Ocean port and carrier selection is formulated as minimum cost maximum flow and prototyped with the cycle cancelling algorithm. And finally inland transportation mode and carrier selection is formulated as variable sized bin packing with costs and is solved by a proposed heuristics algorithm. The second approach is a backtracking approach aimed at getting the optimal solution for smaller problem instances and establishing a baseline to compare solutions obtained by the first approach.

Both approaches are implemented as prototypes and evaluated with historical real world data provided by a large food export company. For all data sets, both prototypes produce

solutions with transportation cost less than that obtained by the company manually. On average the prototypes reduce the cost by 3% and save $30,000 for each data set. The three stage solution approach prototype runs much faster than the backtracking approach prototype. For almost all larger data sets, it takes too long for the backtracking prototype to complete. If we let the backtracking prototype run for 30 minutes and keep the best solution, the solutions obtained by both prototypes are comparable in terms of their cost. As for time, the three stage solution approach prototype takes about 2 seconds to obtain each solution.

This thesis is approved for recommendation
to the Graduate Council.

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1. INTRODUCTION

With globalization and free trade agreements, import and export of goods has become a critical aspect of economic development. Logistics plays an important role in distribution of products domestically as well as internationally. As per Herbert W. David and Company, Logistics Cost and Service Survey, 2010 logistics cost make up 8% of total costs of operations. Transportation makes up 30% of that 8% of the cost. Companies worldwide are investing in Transportation Management Systems to optimize equipment usage and reduce costs. The basic functions of transportation management systems include order consolidation (combining of multiple orders on a single transportation resource), transportation mode selection (rail vs truck etc.), vehicle routing, selection of a transportation service provider, selection of a driver for the vehicle, capturing opportunities to keep the vehicle moving to minimize empty transportation legs subject to business rules or constraints. Some of these transportation functions like driver selection, minimizing the empty transportation legs are only relevant to companies that own a fleet of vehicles and are not the focus of this Thesis.

Intermodal transportation can be defined as the movement of goods from origin to destination using two or more transportation modes such as road, rail, air, inland water or ocean [13]. The export intermodal transportation problem in this study focuses on overseas exports of goods using multiple transportation modes thus involving transshipment locations. A transshipment location is defined as a location where goods are moved from one mode of transportation to a different mode of transportation. Goods are typically not stored at a transshipment location for a very long time. An inland location can be defined as a location that is not a port (seaport or airpoit) and thus requires transportation modes like rail or truck to move goods to the port for overseas export. The transportation modes available for overseas export are air and ocean. The cost of air transportation is considerably more than the cost of ocean transportation making ocean transportation preferable for overseas exports.

In a typical instance of export intermodal transportation problem the goods are transported from an inland location to a transshipment location which in this case is a seaport location using transportation mode like rail, truck etc. We will call this seaport location an origin port. The goods are then trans-loaded into ocean containers which are then transported to the destination port using cargo ships. If the destination port is not the final destination for the goods then they are transported to an inland destination location using truck or rail. The ocean transportation leg is called the main carriage. The inland leg preceding the main carriage is called pre carriage. The inland leg following the main carriage is called the post carriage or on carriage. The export intermodal transportation problem needs to reduce the overall cost of transportation for transporting goods from origin location to destination location. The overall cost may be reduced by consolidating orders, choosing the appropriate mode of transportation and carrier for moving goods from inland location to the origin port, choosing the appropriate origin port and ocean carrier subject to the business rules or constraints. Some of the constraints that influence the transportation planning decisions are product availability at an inland location, service schedules for transportation modes like rail and ocean, transit times, service availability, number of vehicles available, size of the vehicles available, minimum quantity commitments with the carriers, loading and unloading capacities at different locations etc.

The export intermodal transportation problem is faced by two different types of companies. The first type is the shipper companies that are planning transportation for moving their own goods. Their main focus is to reduce the overall cost of moving goods by efficiently consolidating orders and selecting the appropriate inland and ocean carriers meeting the constraints. The second type is the logistics service providers who receive transportation requests from different shipper companies. Their main focus is to reduce cost by efficiently consolidating requests, minimizing the number of vehicles used and minimizing the empty travel of their vehicles. The export intermodal transportation problem in this study is focused on the shipper scenario.

1.1 Export Intermodal Transportation Problem

Given a set of orders, a set of inland transportation resources, a set of ocean container resources and port capacity, find the least cost solution to transport all orders from origin location to destination location. Each order in the set is specified by its origin location, destination location, size, start time and delivery time also refered to as end time. An inland transportation resource is specified by its origin location, destination location, mode of transportation, carrier, size and cost. Origin port, destination port, carrier and cost are specified for each ocean container resource. The port capacity is defined as the maximum number of containers that an ocean carrier can ship at an origin port. The detailed problem formulation is described in Chapter 3.

1.2 Objective

The main objectives of this thesis are:

- Study the export intermodal transportation problem and formulate as a computational problem.

- Create a prototype of the backtracking approach for the export intermodal transportation problem to establish a baseline to compare solutions obtained by other approaches and to obtain optimal solutions for smaller problem instances.
- Create a prototype of the proposed three stage solution approach for the export intermodal transportation problem that runs in polynomial time and returns a near optimal solution.
- Analyze the results based on real historical data sets from the backtracking approach, the proposed three stage solution approach and manual transportation planning.

1.3 Organization of this Thesis

Chapter 2 covers the motivation, background and related work about this problem. Chapter 3 discusses the problem formulation and solution approach. Prototype details are discussed in Chapter 4. Chapter 5 presents the data analysis, results of various prototypes and comparison with manual planning solution. Chapter 6 closes with conclusion and future work.

2. BACKGROUND

2.1 Glossary

Below are some of the terms that are widely used in the logistics and transportation industry and are referred to in this study.

- **Order** – Customer demand for goods.
- **Overseas export order** – Order that requires air or ocean transportation.
- **Containers** – Equipment that holds goods and can be transported via truck, rail or ocean.
- **Resource** – Equipment, vehicle or container used to transport goods.
- **Consolidation** – Combining multiple orders on a single resource.
- **Deconsolidation** – Distributing the orders from a single resource to multiple resources. Example: Goods from a railcar are transferred into several containers.
- **Intermodal** – Movement of goods that requires multiple transportation modes like rail, truck, ocean etc.
- **Transloading** – Transfer of goods due to transportation mode change. Example: Goods are transloaded at ports from trucks into ocean containers.
- **Transshipment locations** – An intermediate location which is not the final location of delivery. Typically such locations are used for transloading, consolidation or deconsolidation.
- **Service schedules** – Schedule of service published by carriers.
- **Transit time** – Time required to travel from a location to another location.

- **Minimum quantity commitments (MQC)** – Minimum number of vehicles that the shipper will utilize during the contract period. If the MQC is not met then penalties could be applied for every vehicle not utilized.
- **Shipper** – Party responsible for initiating the shipment (movement of goods). In the context of this Thesis it is the party responsible for packaging the goods, consolidation and transportation of goods only for self and not providing it as a service to other companies.
- **Logistics service provider** – Party or company that provides logistics services to its customers. Services range from complete warehousing, packaging, planning, transportation and tracking of goods to only receiving transportation requests and delivering goods.
- **Loading and unloading** – Activities of loading or unloading the goods at a location.
- **Inland carriers** – Carriers providing land transportation. Example: Railcar, truck etc.
- **Ocean carriers** – Carriers providing ocean transportation. Some ocean carriers own containers and cargo ships whereas others only own containers and use other carrier’s cargo ships. For the purpose of this study it is irrelevant if the ocean carrier owns a cargo ship or uses other carrier’s cargo ship.
- **Financial credit terms** – Method of payment for the order. Some of the methods available are letter of credit, wire transfer, 30% before shipping and 70% before delivery etc.
- **Transportation zone** – This is either a group of locations, a region or group of regions. Example: State of Arkansas or all the ports in the Los Angeles area etc.

- **Transportation Lane** – A lane connects locations or transportation zones such that transportation is available between the start location/zone to end location/zone.
- **Service attributes** – This is typically a list of service related attributes like direct service from origin to destination port vs indirect service that has several ports of call.

2.2 A Real World Export Intermodal Transportation Problem

The shipper companies typically receive the overseas export orders 3 to 4 weeks prior to delivery date because of longer transit times, financial credit terms, export documentation requirements etc. The orders are handed over to the logistics department a week before they are ready to be shipped out of the warehouse or production facility (this is typically an inland location) based on goods availability and other constraints. The orders typically have a date they should be shipped on, date they should be delivered by, goods information like quantity, category (dry, bulk, refrigerated, frozen etc.), location it will be shipped from, location it needs to be delivered to. Based on the type of the goods and contracts with the customers the delivery date could be a hard requirement or a tolerance of certain days could be allowed. Based on the warehouse/production facility that the goods need to be shipped from, different modes of transportation are available. For example, rail is only available at certain locations whereas truck transportation is typically available at all locations. The large shipper companies typically have contracts with the inland and ocean carriers. The contract terms include the cost of transportation for every transportation lane that the carrier offers service on, service attributes, transit, minimum quantity commitments, weekly allocation and penalties if minimum quantity commitment is not met, etc. A transportation lane can be defined as a location to location lane or a zone to zone. An example of location to location transportation lane would be warehouse XYZ, Springdale, AR to warehouse ABC, Chicago, IL whereas an example of zone to zone transportation lane would be Northwest Arkansas to South Illinois. The logistics department has to find a least cost solution to transport all the goods from origin to destination. Based on the international export/import regulations the demand of customer orders is volatile. For example a country could ban import of a certain goods. Based on weather and political situations the supply of ocean containers and service on ocean transportation lanes is volatile. For example hurricane on the gulf coast could shut down certain origin ports. Incorporating all these criteria and planning transportation manually to get the least cost solution for all orders is a very difficult to an impossible task. The problem of finding an optimal solution for transporting all overseas export orders from origin location to destination location without violating any constraints is the export intermodal transportation problem. This is a special case of intermodal transportation problem as the overseas export orders must require air or ocean transportation. An intermodal transportation problem has no restriction on transportation modes or number of transfers.

2.3 Related Work

The Truck Dispatching Problem [1] was first introduced by Dantzig et.al. The truck dispatching problem studies the order consolidation and assignment of trucks to locations (vehicle routing) to minimize the miles travelled by all trucks thus minimizing the total cost. Even though it did not study all transportation functions described in the introduction of this thesis, it was the first to bring attention to this problem. This problem is also called as the vehicle routing problem (VRP) and is described as a generalization of a well-known problem The Travelling Salesman Problem [4]. The travelling salesman problem gets its name from the scenario of a salesman wanting to travel shortest distance or shortest time starting from his home and visiting the list of cities exactly once and returning to his home. In the vehicle routing problem every vehicle could be equated to a salesman and every city to visit could be equated to the locations the vehicle will visit. The vehicle routing problem only uses a single size of vehicle thus not taking into consideration different transportation modes and only allows movement between supply and demand points.

Several researches have extended the VRP into other problem classes like VRP with time windows, capacitated VRP, capacitated VRP with time windows, pickup and delivery problems with time windows and open vehicle routing problem. Venkatesh et.al [7], B.Chandra et.al [9], Bortfeldt, Andreas [10], T.K.Ralph et.al [11] and Szeto et.al studied the capacitated vehicle routing problem. The capacitated vehicle routing problem extends the vehicle routing problem by taking into consideration the size of the vehicle. A problem of selecting rail vs truck etc can be mapped to capacitated vehicle routing problems as every resource has a different cost and these problems focus of minimizing the total cost. When compared to the export intermodal transportation problem, these problems do not allow for transshipment locations and do not consider carrier selection. Also in all of the above studies the vehicle starts and ends at the depot (the same location) which typically applies to the transportation functions of companies that own a fleet of vehicles.

Sariklis et.al [6] and Jose Brandon [5] studied the open VRP which if different from the other vehicle routing problems as the vehicle starts at a depot but is not required to return to the depot. A depot is any location where vehicles are parked and/or available. The objective of these problems is to minimize the travel and vehicle operating cost. The vehicle starts at a location and visits as many customer locations as possible to deliver good based on the vehicle capacity. The study assumed the customer demand to be less than or equal to vehicle capacity. They used clustering to consolidate demands from multiple customers into a single vehicle and in doing so minimized the transportation costs and maximized the vehicle capacity. This heuristic performs particularly well on problems with small number of customers per route. Again these problems solved the consolidation and routing problem and supported multiple vehicle sizes which would allow these to be used for transportation mode selection. These problems did not focus on intermodal transportation with transshipment location or carrier selection.

As defined earlier intermodal transportation involves two or more transportation modes. Huacan et. all [13] focused on three characteristics of an intermodal problem: transportation mode sequence to make sure the routes were feasible in the real world, number of modal transfers (number of modes for moving goods) and a generalized cost function which can be defined as travel cost or travel time. To explain the transportation mode sequence characteristic better consider an example with two inland locations. Then the mode sequence consists of an ocean transportation mode followed by a truck transportation mode to transport goods between those locations is not a valid transportation sequence. This study focus on intermodal transportation and routing but does not allow for consolidation or deconsolidation of orders on modal transfers and assumes that the goods are moved as a single unit size from origin to destination. Hyung Cho et.al [14] studied the intermodal transportation problem and applied a dynamic programming. They focused on minimizing travel cost and time, multiple transportation modes and one or more constraints related to time, cost or capacity. They also pointed out that typically international mode of transportation like ocean and air have a fixed schedule and more constraints so need to be picked first and then the inland transportation modes. This work relates closely to the problem studied in this Thesis but differs due to consolidation/deconsolidation of goods across different modes and carrier selection. Qingbin et.al [15] modeled the container multimodal transportation network and used a shortest path algorithm to solve the problem. In this paper the container unit is transported on different modes of transportation and thus the goods were again transported as single unit from origin to destination. This only allows for consolidation of orders with same origin and destination and does not allow consolidation/deconsolidation at transshipment locations. This problem also assumes that between two locations only a single mode of transportation exists and thus cannot perform the transportation mode selection function. Infante et.al [19] studied the ship-truck intermodal transportation problem whereas Arnold et.al [12] studied the rail-truck intermodal transportation problem.

Mues et. al [16] formulated the intermodal transportation problem with time windows as a linear program and applied the column generation technique. They studied the simplification of the problem by restricting the number of transshipment points to 1. Using a heuristic to generate columns and then solving the mixed integer programming problem they produced solutions in 2 to 6 minutes for 70 loads [16]. This thesis also uses a similar simplification of the export intermodal transportation problem to limit the number of transshipment points to 1 and applies a combination of network flow and bin packing techniques to solve the problem. Data analysis and run time details are discussed in later chapters.

2.4 Computational Background

Different computational problems that are used or referenced in this thesis are described in this section.

2.4.1 Bin Packing Problem [20]

Given items with sizes s_1, s_2, s_3..s_n and bins B_1, B_2.. B_m of single size S, find the assignment of items to the bins such that sum of sizes of all items in a single bin do not exceed the size of the bin and the number of bins used is minimized. Some of the real world problems that can be formulated as bin packing problem are order consolidation into vehicle of a given size, creating file backup on removable media, scheduling of resources to tasks where every task has a defined time required to perform it etc. Order consolidation on ocean container, which is introduced in the proposed three stage solution approach in section 3, is modeled as bin packing.

2.4.2 Variable-Sized Bin Packing Problem [17]

Variable-sized bin packing problem is a variant of the classic bin packing problem in which different sizes of bins are allowed. Given a list of n items with sizes s_1, s_2, s_3..s_n , k bin types T_1, T_2, T_3..T_k and unlimited number of bins of each type, find the assignment of items to the bins such that sizes of all items in a single bin do not exceed the size of the bin and the sum of sizes of bins used is minimized.

2.4.3 Variable-Sized Bin Packing Problem With Fixed Costs [18]

In this problem a finite set of items must be packed in finite number of heterogeneous bins, characterized by different sizes and costs. The objective is to pack all items in bins while minimizing the total cost, which is the sum of bin costs for bins used. Note that if the cost of a bin is the size of the bin, the variable-sized bin packing problem reduces to the variable-sized bin packing with cost problem. The bin selection heuristic defined by Crainic et.al [18] sorts the bins in non-decreasing order of cost per unit size and in non-increasing order of size when cost per unit size is the same. The orders are sorted in non-increasing order of size. An existing bin is used such that it has maximum free space after the item is assigned. If an existing bin is not found then first bin in the ordered list of bins is selected. They recognized that cost per unit size might not be a good parameter if the size of unpacked items cannot utilize the volume of the bin. The absolute smallest cost is a better option in that situation. They implemented a post processing procedure that swapped the high volume bins for the absolute smallest cost bins. This heuristic does not consider an item size greater than bin size. Inland transportation mode and carrier selection, which is introduced in the proposed three stage solution approach in section 3, is modeled as variable-sized bin packing with cost. A new heuristics is proposed in section 4 to solve the variable-sized bin packing with cost problem.

2.4.4 Maximum flow problem [21]

A flow network G = (V, E) is a directed graph in which each edge (u, v) ∈ E has a non-negative capacity c(u, v) ≥ 0. A flow is defined as real valued function f: E → R such that f (u, v) ≤ c(u, v) and $\sum_{(v,u)\in E} f(v,u) = \sum_{(u,w)\in E} f(u,w)$ for all u ∈ V – {s, t} where s and t are source and sink vertices. The value of a flow in a network is defined by the flow leaving the source or the flow entering the sink. Given a flow network G, source s and sink t find the flow of maximum value.

Some of the applications of maximum flow problem are network capacity planning, airline scheduling, vehicle routing etc.

2.4.5 Minimum cost maximum flow problem [21]

Given a flow network G = (V, E) such that each edge (u, v) ∈ E has a non-negative capacity c(u, v) ≥ 0 and a non-negative cost m(u, v) ≥ 0 find the flow of maximum value with minimum cost. If f (u,v) is the flow on edge (u, v) then the cost of the flow is defined as:

$$cost(flow) = \sum_{(u,v)\in E} f(u,v)\ x\ cost(u,v)$$

Ocean port and carrier selction, which is introduced in the proposed three stage solution approach in section 3, is modeled as minimum cost maximum flow. The prototype solves the problem by first solving maximum flow using preflow algorithm and then using cycle cancelling algorithm to find the minimum cost maximum flow.

2.4.6 Shortest path problem [23]

Given a weighted, directed graph G(V, E), with weight function w: E → R mapping edges to real valued weights. The weight of path p = (v_0, v_1, v_2..v_k) is the sum of weight of its constituent edges: w(p) = $\sum_{i=1}^{k} w(v_{i-1}, v_i)$. The shortest path weight from u to v is defined as

$$\delta(u,v) = \begin{cases} \min\left\{w(p): u \overset{p}{\to} v\right\} & if\ there\ is\ a\ path\ from\ u\ to\ v \\ \infty & otherwise \end{cases}$$

A shortest path from vertex u to v is then defined as any path p with weight w(p) = $\delta(u,v)$. There are several variants of the shortest path problem like single source all destinations shortest path, single pair shortest path, all pair shortest path. In some instances of the shortest path problems negative weight edges may exist. A cycle is a closed path that starts and ends at the same vertex. Shortest path problems assume that there are no negative weight cycles in the graphs. Some of the shortest path algorithms like the Bellman-Ford algorithm can be used to detect negative weight cycles in the directed graph, which is used in the cycle canceling algorithm in the prototype

2.4.7 Backtracking

Backtracking is a well-known problem solving technique that performs an exhaustive systematic search based on the value of defined bounding function. This technique has been defined in great detail by Horowitz and Sahni [24]. A solution approach and its prototype are developed based on backtracking. The details are presented in chapters 3 and 4.

3. PROBLEM FORMULATION AND APPROACH

3.1 Motivation

The Export Intermodal Transportation Problem is based on a real world export intermodal transportation problem faced by a large shipper company. The challenge faced by the logistics department of this shipper company is to find the least cost solution for transporting orders from origin to destination given the capacity constraints, date/time constraints and volatile demand and supply.

3.2 Export Intermodal Transportation Problem

Typically overseas export orders are received by the companies 30 days in advance due to the time required to transport goods overseas, international regulations and other reasons. Important order attributes that drive transportation decisions are weight, volume, type of goods (liquid, refrigerated, fragile etc.), warehouse where the goods are or will be available, date and time when goods will be available, destination, date and time of delivery at the destination.

As defined in earlier sections a transportation lane connects two locations or transportation zones such that transportation is available from the start location/zone to the end location/zone. Several transportation modes could be available for a transportation lane for example rail, truck etc. Further within a transportation mode there could be different resource sizes available for example jumbo railcar is 1.5 times the size of the standard railcar. Another example is the tractor trailer vs a container on the flatbed truck as shown in Figure 2 and Figure 1 respectively. Typically multiple carriers service every transportation lane. A unique inland transportation resource is defined by origin location, destination location, transportation mode, size, carrier and cost.

Figure 1 – Container on a flatbed truck

Figure 2 - Tractor trailer

Similarly varieties of containers are available for ocean transportation. For example: refrigerated 20 foot container, refrigerated 40 foot container, dry 40 foot container etc. Other ways of loading cargo on the ship like bulk and break bulk are not in scope of this study. An example of bulk loading is oil or grain directly loaded in the hull of the ship. An example of break bulk is individual goods like barrels or boxes directly loaded in the hull of the ship.

Important resource attributes that drive transportation decisions are legal limits for weight and volume, transportation mode and resource size (flatbed trailer, refrigerated trailer, tanker, hopper, dry container, refrigerated container, jumbo railcar etc.), number of resources available, carrier and cost. Certain resources like truck do not have a fixed schedule. The transportation can start and end at any time. The important attribute in this case is the time required for the truck to travel from origin location to destination location which is also referred to as transit time. Whereas resources like railcars and ships have a fixed delivery schedule meaning that the start and end times are fixed. A schedule also has additional attributes like direct versus indirect service which indicates if the resource travels directly from origin location to destination location or has intermediate locations, cargo cut-off date which is the date by which cargo should be handed over to the carrier which is typically 24 to 48 hours before the resource start time. The resource transit or schedule also is an attribute of the resource. For ocean containers the resource capacity is defined by origin port and carrier. For example: The resource capacity for ocean carrier C1 at origin port P1 is 50 ocean container resources week. Ocean carrier C1 services destination ports D1, D2 and D3 from origin port P1. The sum of containers that can be shipped by ocean carrier C1 from P1 to D1, P1 to D2 and P1 to D3 cannot be greater than 50.

Transloading service is typically used to transfer goods from railcar into container or truck into container. The costs of these transloading services are significantly lower than the inland and ocean transportation costs and thus typically do not drive transportation decisions. For this reason the transloading service costs are not included in the problem formulation.

Thus the export intermodal transportation problem is defined as the problem of finding an optimal solution for all given overseas export orders without violating the resource and date/time constraints.

Every order should be transported from the origin location to the destination. A unique inland transportation resource is defined by start location, end location, transportation mode, carrier, start time, end time and resource identifier. Similarly unique ocean container resource is defined by start location, end location, carrier, start time, end time and resource identifier.

The assignment of an order to the inland transportation resource is acceptable only if the following constraints are met: start time of order is at or before the start time of the inland transportation resource, end time of the order is after the end time of the inland transportation resource, start location of the order is the same as the start location of the inland transportation resource, size of the order is less than or equal to the size of inland transportation resource.

The assignment of an order to the ocean container resource is acceptable only if the following constraints are met: end time of the order is at or before the end time of the ocean container resource, start time of the container is at or after the end time of the inland transportation resource, end location of the order is the same as the end location of the ocean container resource, start location of the ocean container resource is the same as the end location of the inland transportation resource and size of the order is less than or equal to the size of the ocean container resource.

The resource identifier is a sequence that helps identify order consolidation. When multiple orders are assigned to a single resource it represents consolidation. The sum of the sizes of all orders assigned to a resource is less than or equal to the size of the resource. A resource is considered utilized when at least one order is assigned to it. Port capacity is defined as the number of containers available for an ocean carrier at an origin port. The number of utilized resources for a combination of ocean carrier and origin port is less than or equal to the port capacity for that ocean carrier and origin port. Example: port capacity for carrier C1 at origin port P1 is 10 containers. Ocean container resources available are: 8 resources with carrier C1 from origin port P1 to destination port D1 and 10 resources with carrier C1 from origin port P1 to destination port D2. The sum of utilized resources should be less than or equal to 10.

Any set of assignments that meets the above constraints is a feasible solution. Inland and ocean cost are calculated for every utilized resource. The sum of inland and ocean costs for all utilized resources is the total cost of the solution. A feasible solution with minimum total cost is the optimal solution for the problem

3.3 Formal Formulation

In export intermodal transportation problem, we have the following: order set, inland transportation resources, ocean container resources, and carrier port capacities. Without loss of generality, integers are used for size and time, which are multiples of some basic unit.

Each order is characterized by the following:

i. origin: This is the place where the goods are available for shipment. It is either a warehouse or production plant in the country of export. An integer is used to represent an origin.

ii. destination: This is the place where goods are delivered in the country of import. An integer is used to represent the destination.

iii. size: This is the size of the order in terms of the basic unit.

iv. start-time: This is the time after which the order will be available.

v. end-time: This is the time before which the order must be delivered.

Formally, the order set is $O = \{o_i \mid 1 \leq i \leq n\}$, where origin($o_i$) denotes the the origin of o_i, destination(o_i) denotes the destination of o_i , size(o_i) denotes the size of o_i , start-time(o_i) denotes the start time for o_i and end-time(o_i) denotes the end time for o_i.

Each inland transportation resource is characterized by the following:

i. origin: This is the place where the transportation resource picks up goods to be transported. An integer is used to represent this origin.

ii. destination: This is the place where the transportation resource drops off goods that are transported from the origin. In the context of this thesis this represents the port of export. An integer is used to represent the destination.

iii. size: This is the size of the transportation resource in terms of the basic unit, which indicates the maximum amount it can carry.

iv. cost: This is the cost of using the transportation resource from origin to destination.

v. carrier: This is the owner of the transportation resource providing the transportation service.

vi. start-time: This is the time at which the resource is available. Start time is typically defined for resources that have a fixed schedule. The resource starts transportation at this time.

vii. end-time: This is the time at which the resource arrives at the destination as per the schedule.

viii. transit-time: This is the time it takes to transport goods from origin to destination.

Formally, the transportation resource set is $T = \{t_i \mid 1 \leq i \leq m\}$, where origin ($t_i$) denotes the origin of t_i , destination(t_i) denotes the destination of t_i , size(t_i) denotes the size of t_i , cost(t_i) denotes the cost for t_i, carrier(t_i) denotes the carrier for t_i, start-time(t_i) denotes start time for t_i, end-time(t_i) denotes end time for t_i and transit-time(t_i) denotes transit.

Each ocean container resource is characterized by the following:

i. origin: This is the place where the container is loaded or filled before the ocean shipment. In the context of this thesis it is the port of export. An integer is used to represent the origin.

ii. destination: This is the place the container is delivered after the ocean shipment. An integer is used to represent the destination.

iii. size: This is the size of the container in terms of the basic unit, which indicates the maximum amount it can carry.

iv. cost: This is the cost of using the ocean container resource to transport goods from origin to destination.

v. carrier: This is the owner of the container and provides the transportation service from origin to destination.

vi. start-time: This is the time the container leaves the origin. Ocean containers are transported on cargo ships and cargo ships have published schedules. The cargo ships leave the port at the start-time.

vii. end-time: This is the time the container reaches the destination as per the schedule for the cargo ship it is transported on.

Formally, the ocean container resource set is $C = \{c_i \mid 1 \leq i \leq k\}$, where origin (c_i) denotes the origin of c_i , destination(c_i) denotes the destination of c_i , size(c_i) denotes the size of c_i , cost(c_i) denotes the cost for c_i, carrier(c_i) denotes the carrier of c_i, start-time denotes the start time for c_i and end-time(c_i) denotes the end time for c_i.

A solution involves assigning T and C to O such that various constraints are met. More specifically, let $x_{i,j}$ denote whether t_j is assigned to o_i or not. A value of 1 means it is assigned, 0 means it is not assigned, and a value δ between 0 and 1 means a δ fraction is assigned to o_i . Let $y_{i,j}$ denote whether c_j is assigned to o_i or not. A value of 1 means it is assigned, 0 means it is not assigned, and a value δ between 0 and 1 means a δ fraction is assigned to o_i.

The constraints are grouped into size constraints, location constraints, time constraints and resource limit constraints. In plain English, the size constraints specify the inland and ocean resources assigned to each order are sufficient and that no resource is assigned more than what its size can handle. Sufficient inland resources are assigned for an order is given by constraint (1) and no inland resource is assigned more than its size is given by constraint (2). Similar constraints (3) and (4) are defined for ocean transportation leg.

$$size\,(o_i) \le \sum_{j=1}^{m} size(t_j) * \; x_{i,j}, 1 \le i \;\le n \tag{1}$$

$$\sum_{i=1}^{n} x_{i,j} \;\le 1,\;\; 1 \le j \;\le m \tag{2}$$

$$size\,(o_i) \le \sum_{j=1}^{k} size(c_j) * \; y_{i,j}, 1 \le i \;\le n \tag{3}$$

$$\sum_{i=1}^{n} y_{i,j} \;\le 1,\;\; 1 \le j \;\le k \tag{4}$$

In plain English the location constraints specify that all inland resources assigned to an order match in origin with the order. Further the destination for the inland resources for an order matches the (export port) origin of the ocean resource for the order. And finally the ocean resources assigned to the order match in destination with the order. Origin match for inland resources is captured by (5).

$$origin(o_i) = origin(t_j),\, 1 \le i \le n,\, 1 \le j \le m,\, x_{i,j} \ne 0. \tag{5}$$

To make sure the inland and ocean legs match in location, we have for each order i, $1 \le i \le n$

$$destination(t_j) = origin(c_l),\ 1 \le j \le m,\ 1 \le l \le k,\ y_{i,l} \ne 0,\ x_{i,j} \ne 0 \quad (6)$$

Destination match for ocean resources is captured by (7).

$$destination(o_i) = destination(c_l),\ 1 \le i \le n,\ 1 \le l \le k,\ y_{i,l} \ne 0 \quad (7)$$

If the same order must be shipped to the same origin port, then we will have for each order o_i, $1 \le i \le n$.

$$destination(t_j) = destination(t_l),\ 1 \le j,l \le m,\ x_{i,j} \ne 0,\ x_{i,l} \ne 0 \quad (8)$$

If the same order must be shipped by the same carrier from the same origin port, then we have constraints (9) and (10) for each order o_i, $1 \le i \le n$.

$$\text{carrier}(c_j) = \text{carrier}(c_l),\ 1 \le j,l \le k,\ y_{i,j} \ne 0,\ y_{i,l} \ne 0 \quad (9)$$

$$\text{origin}(c_j) = \text{origin}(c_l),\ 1 \le j,l \le k,\ y_{i,j} \ne 0,\ y_{i,l} \ne 0 \quad (10)$$

Note that if an order is allowed to be shipped to different ports and within a port by different carriers, which is more general, the above may be adjusted accordingly.

The time constraints ensure that the inland transportation resources pick up each order after its start-time, the end-time of the inland transportation resources is ahead of the start-time of ocean contain resources and the ocean container resources deliver each order before its end-time. Formally, we have for each order i, $1 \le i \le n$,

$$start\text{-}time(o_i) \le start\text{-}time(t_j),\ 1 \le j \le m,\ x_{i,j} \ne 0 \quad (11)$$

$$end\text{-}time(t_j) \le start\text{-}time(c_l),\ 1 \le j \le m,\ 1 \le l \le k,\ x_{i,j} \ne 0,\ y_{i,l} \ne 0 \quad (12)$$

$$end\text{-}time(o_i) \ge end\text{-}time(c_j),\ 1 \le j \le k,\ y_{i,j} \ne 0 \quad (13)$$

Let the number of ocean carriers be S and the number of export ports be P. The carrier port capacity is given by $w_{i,j}$, $1 \le i \le S$, $1 \le j \le P$. Let the number of ocean container resources used, in an assignment, by carrier i for port j be $C_{i,j}$. Formally,

$$C_{i,j} = \{c_v \mid origin(c_v) = j,\ carrier(c_v) = i,\ y_{u,v} \ne 0 \text{ for some order } o_u\} \quad (14)$$

$|C_{i,j}| \leq w_{i,j}$, $1 \leq i \leq S$, $1 \leq j \leq P$ (15)

An assignment, which determines values for x and y variables, is a feasible solution if all the above constraints are met. Let the set of inland transportation resources used be A and the set of ocean container resources used be B for a feasible solution. We have:

$A = \{t_j \mid x_{i,j} \neq 0 \text{ for some order } o_i\}$

$B = \{c_l \mid y_{i,l} \neq 0 \text{ for some order } o_i\}$

The cost of feasible solution is given by:

$$\sum_{t \in A} cost(t) + \sum_{c \in B} cost(c) \quad (16)$$

Among all feasible solutions those have the least cost are optimal solutions

3.4 Example

Table below defines the order data. We consider only 2 inland locations 1 and 2, two origin ports 1 and 2 and 4 destinations 1, 2, 3 and 4. In this example all the ocean container resources are of the same size and that size is considered to be 1 unit. The order sizes and inland transportation resource sizes are defined in terms of that unit.

Order	Start location	End location	Size in units	Start time	End time
1	1	1	0.66	1	10
2	1	1	0.33	1	10
3	1	2	0.66	1	10
4	1	2	0.33	1	10
5	2	1	1	1	10
6	2	2	1	1	10
7	2	2	1	1	10
8	2	3	1	1	10
9	2	4	1	1	10

10	2	4	1	1	10

The table below lists the ocean container resources available from origin port (export port) to destination with costs. Start location is the origin port and end location is the destination port.

Start location	End location	Ocean Carrier	Size in units	Cost per unit	Start time	End time	Resource identifier
1	1	1	1	90	6	9	1
1	1	2	1	100	6	9	2
1	1	2	1	100	6	9	3
1	2	1	1	90	6	9	4
1	2	2	1	100	6	9	5
1	3	2	1	100	6	9	6
1	3	1	1	140	6	9	7
1	4	2	1	120	6	9	8
1	4	3	1	110	6	9	9
1	4	3	1	110	6	9	10
2	1	3	1	90	6	9	11
2	1	2	1	100	6	9	12
2	2	1	1	90	6	9	13
2	2	1	1	90	6	9	14
2	2	3	1	100	6	9	15
2	4	1	1	120	6	9	16
2	4	3	1	110	6	9	17

The table below lists the resource limits/port capacity for ocean carriers at each port. The resource limits are not defined for each ocean container resource but defined only by start location for a carrier irrespective of the end location.

Start location	Carrier	Number of resources
1	1	2
1	2	3
1	3	2
2	1	2
2	2	2
2	3	3

The table below lists the inland transportation resources.

Start location	End location	Mode	Size	Carrier	Cost	Resource identifier	Transit in days	Start time	End time
1	1	Truck	0.66	T1	30	1	5	1	5
1	1	Truck	0.66	T1	30	2	5	1	5
1	1	Truck	0.66	T1	30	3	5	1	5
1	1	Truck	0.66	T1	30	4	5	1	5
1	1	Container Truck	1	SC1	50	5	5	1	5
1	2	Truck	0.66	T1	32	6	5	1	5
1	2	Container Truck	1	SC1	50	7	5	1	5
2	1	Truck	0.66	T2	32	8	5	1	5
2	1	Container Truck	1	SC1	50	9	5	1	5
2	2	Truck	0.66	T2	31	10	5	1	5
2	2	Container Truck	1	SC1	50	11	5	1	5
2	1	Jumbo Railcar	3	R1	96	12	NA	2	5
2	2	Jumbo Railcar	3	R1	96	13	NA	2	5
2	1	Standard	2	R1	70	14	NA	2	5

		Railcar							
2	2	Standard Railcar	2	R1	70	15	NA	2	5

The table below shows the order assignment to the ocean container resources. Multiple orders assigned to the same resource indicate consolidation.

Start location	End location	Ocean Carrier	Size in units	Cost per unit	Start time	End time	Resource identifier	Orders assigned
1	1	1	1	90	6	9	1	1, 2
1	2	1	1	90	6	9	4	3, 4
1	3	2	1	100	6	9	6	8
1	4	3	1	110	6	9	9	9
1	4	3	1	110	6	9	10	10
2	1	3	1	90	6	9	11	5
2	2	1	1	90	6	9	13	6
2	2	1	1	90	6	9	14	7
				680				

Based on the order assignment the number of utilized resources by ocean carrier and origin port are listed in the table below.

Origin port	Carrier	Number of resources	Number of utilized resources
1	1	2	2
1	2	3	1
1	3	2	2

2	1	2	2
2	2	2	0
2	3	3	1

The table below shows the order assignment to the inland transportation resources.

Start location	**End location**	**Mode**	**Size**	**Carrier**	**Cost**	**Resource identifier**	**Order assignment**
1	1	Truck	0.66	T1	30	1	1
1	1	Truck	0.66	T1	30	2	3
1	1	Truck	0.66	T1	30	3	2, 4
2	1	Jumbo Railcar	3	R1	96	12	8, 9, 10
2	2	Jumbo Railcar	3	R1	96	13	5, 6, 7
					282		

The sum on inland and ocean costs for utilized resources = 680 + 282 = 1052

3.5 A Three Stage Solution Approach

This problem is NP Hard just like most of the problems discussed in the literature review. This study divides the problem into three sub problems of order consolidation on ocean transportation leg, ocean carrier and origin port selection and then inland carrier selection with order consolidation. It is generally observed that the cost of ocean transportation is greater than the cost of inland transportation and thus the solution approach starts with ocean transportation solution first and then tackles the inland transportation solution.

The following assumptions are made:

1. Time windows constraint is relaxed and the problem is formulated without time windows, meaning that the start and end times for orders, inland resources and ocean resources are not considered.
2. Inland transportation resource starts at an inland location and ends at origin port and ocean container resource starts at the origin port and ends at the destination port. Every order starts at an inland location and ends at a destination port and has exactly one inland transportation leg and one ocean transportation leg.
3. Size of all ocean container resources is the same and is considered to be 1 unit and the size of orders and inland resources is defined in terms of this unit.
4. Size of any given order is 1 unit or less than 1 unit. If order size is greater than 1 unit then that order will be split into multiples of 1 unit and the remainder order using a pre-processing step before entering it as an input to the prototype programs.

Ocean resource cost is calculated as cost per ocean container resource. Minimizing the number of ocean container resources used will reduce cost.

Orders with different destination ports cannot be combined into a single ocean container resource as the resource starts at an origin port and ends at one destination port. Thus the orders with the same destination are grouped into subsets of orders. The problem of order consolidation on ocean transportation leg for each destination is formulated as a classic bin packing problem.

Remember, the objective of bin packing problem is to minimize the number of bins used, which in this case translates into minimizing the number of ocean container resources used.

Bin packing returns the number of containers to be moved to destination ports. Several choices are available for moving containers to a given destination port. Ocean transportation is available from various origin ports to a destination port, thus the first decision is to choose an origin port to move the containers from. Further, several different ocean carriers provide service from an origin port to destination port, thus the next decision is to choose the ocean carrier to use. The ocean carrier choices available in this step depend on the origin port selected in the first step. To illustrate this let us consider an example of transporting containers to Hong Kong. Containers can be transported from various origin ports like Los Angeles or Oakland or Seattle. Carriers C1, C2 and C3 provide service from each of these ports to Hong Kong. Thus there are total 9 ways to move containers to Hong Kong.

The number of ocean containers that a carrier may ship from a port is called the port capacity. The best way, meaning selecting a port and a carrier for each container, to move the containers to the destination port such that the cost is minimized and the port capacity is not violated can be represented as a network flow problem.

The problem can be solved by finding the minimum cost maximum flow for the modeled network flow. The value of maximum flow should be equal to the total number of containers to be moved. Following characteristics are modeled in the network flow: number of ocean containers to be moved to each destination port, origin ports that service the destination ports, ocean carriers that provide service from origin port to destination port with cost of transportation and port capacity that restricts the number of containers that can be shipped from an origin port by a carrier. Each of these characteristic is used to define either capacity or cost for arcs/edges in the network flow.

The following assumes that that inland transportation is available to move the containers (or orders in the containers) from their inland locations to the origin ports determined by the minimum cost maximum flow. Later an enhanced network flow model is introduced that takes inland transportation availibilty into account.

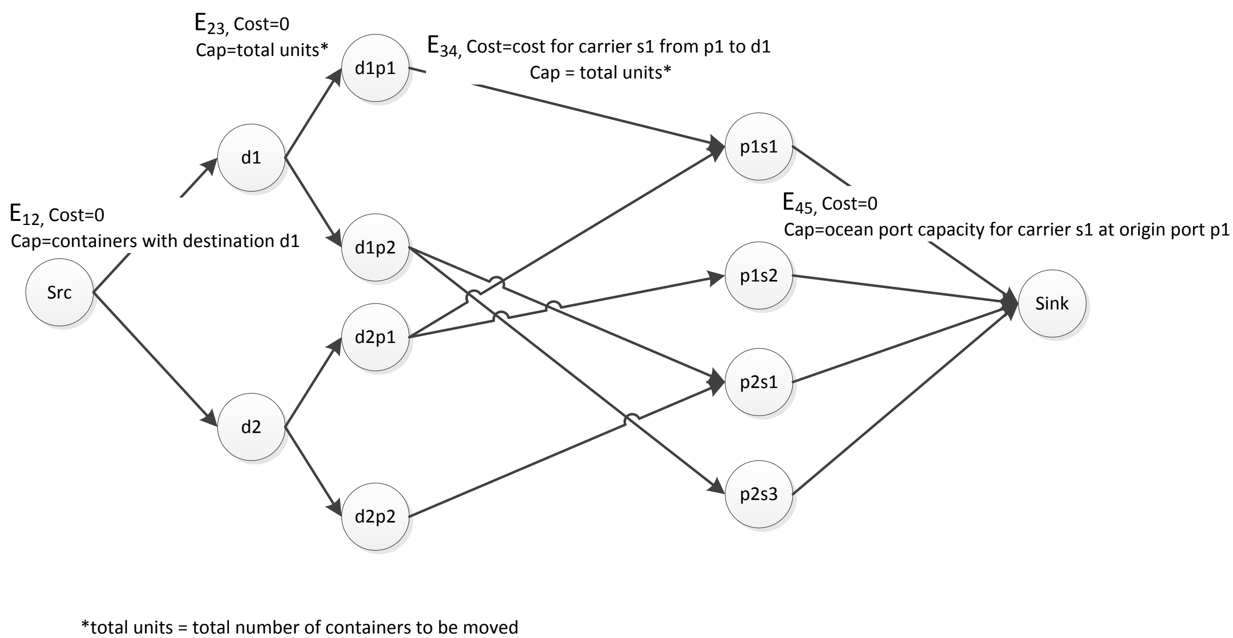

Figure 3 - Network model without inland location nodes

The network model is a directed graph G = (V, E). Every edge (u, v) in the network model has two attributes: cost (u, v) and capacity (u, v). The first characteristic to model in the network flow is to specify the number of containers that need to be moved to each destination. The next level represents the origin ports that have service to the destination port. The arcs leaving the origin port nodes represent the ocean carriers available and the cost of transporting the container from origin port to destination port using that ocean carrier. As the port capacity is restricted by origin port and ocean carrier, all the arcs for a carrier from an origin port converge into a node representing the ocean carrier and origin port. The arcs connecting these nodes to the sink node represent the port capacity.

Let D be the set of destination ports such that at least one container needs to be moved to it. P is the set of origin ports, C is the set of ocean containers and S is the set of ocean carriers. A precise description of the flow network is given below and an example flow network, as an illustration of the construction, is depicted in Figure 3.

Formally the set of vertices at each level can be defined as

Set of vertices at level one; $V_1 = \{src\}$

Level two; $V_2 = \{d \mid d \in D\}$

Level three; $V_3 = \{pd \mid p \in P, d \in D, \textit{origin}\ (c) = p, \textit{destination}\ (c) = d \textit{ for some } c \in C\}$

Level four; $V_4 = \{sp \mid s \in S, p \in P, \textit{carrier}\ (c) = s \textit{ and origin}\ (c) = p \textit{ for some } c \in C\}$

Level five; $V_5 = \{sink\}$

The set of edges/arc connecting vertices from level one to level two is $E_{12} = \{(u, v) \mid u = src, v \in V_2\}$ the cost and capacity are defined as

$\textit{cost}\ (u, v) = 0, (u, v) \in E_{12}$

$\textit{capacity}\ (u, v) = \textit{the number of containers to be moved to } d, (u, v) \in E_{12}, v = d, d \in D$

The set of edges connecting level two to level three vertices is $E_{23} = \{(u, v) \mid u \in V_2, v \in V_3\}$

$\textit{cost}\ (u, v) = 0, (u, v) \in E_{23}$

$\textit{capacity}\ (u, v) = \textit{the number of containers to be moved to } d, \textit{ where } d=u, (u, v) \in E_{23}$

The next set of edges $E_{34} = \{(u, v) \mid u \in V_3, v \in V_4$, origin(c) = p and destination(c)=d and u=pd and carrier(c) = s and v=sp for some $c \in C\}$ represent the ocean transportation cost.

cost (u, v) = cost(c),

$(u, v) \in E_{34}, u = pd, v = sp, c \in C, origin(c) = p, destination(c) = d, carrier(c) = s$

capacity (u, v) = total number of containers supplied by carrier c to ship from port p to destination d, where u= dp and v= sp, $(u,v) \in E_{34}$

Finally, $E_{45} = \{(u, sink) \mid u \in V_4\}$ set of edges connecting level four nodes to sink node represent the port capacity,

$cost\ (u, sink) = 0,\ (u, sink) \in E_{45}$

$capacity\ (u, sink) = w_{ij},\ (u, sink) \in E_{45}, u = s_i p_j,\ 1 \leq i \leq S, 1 \leq j \leq P$

The network flow model above finds for each consolidated container the optimal port, as well as a carrier, to ship the container to minimize the overall cost of the ocean leg provided the inland transportation is available to move the orders in each container from the inland locations to the optimal port. If for some reason the inland transportation is not available to move certain order to certain port, then optimal ocean leg solution cannot be used to realize an overall solution. Let us look at a few examples to illustrate this.

Example 1: In this example an order needs to move from inland location l_1 to destination port d_1. No inland transportation is available from l_1 to origin port p_1 but is available to origin port p_2. The cost of ocean container resource from p_1 to d_1 with carrier c_1 is 80 where as from p_2 to d_1 with carrier c_1 is 100. The minimum cost maximum flow will select the ocean container resource from p_1 to d_1 with carrier c_1 as it is the least cost resource. As there is no inland transportation available from l_1 to p_1, no feasible solution will be found for inland transportation.

Example 2: The second example is with an order from inland location l_1 to destination port d_1 with size of 1 unit. Only one truck trailer transportation with size of 0.66 is available from l_1 to origin port p_1 and container truck with size of 1 unit is available to origin port p_2. Again let the ocean resource costs from p_1 to d_1 with carrier c_1 be 80 where as from p_2 to d_1 with carrier c_1 be 100. The minimum cost maximum flow will select the ocean container resource from p_1 to d_1 with carrier c_1 as it is the least cost resource. Even though inland transportation is available from l_1 to p_1 the size of order is greater than the truck trailer resource and thus no inland solution would be found.

To overcome the issues illustrated with the two examples above, an enhanced network flow model that factors in inland location and resource size is needed and an illustrative example is depicted in Figure 4.

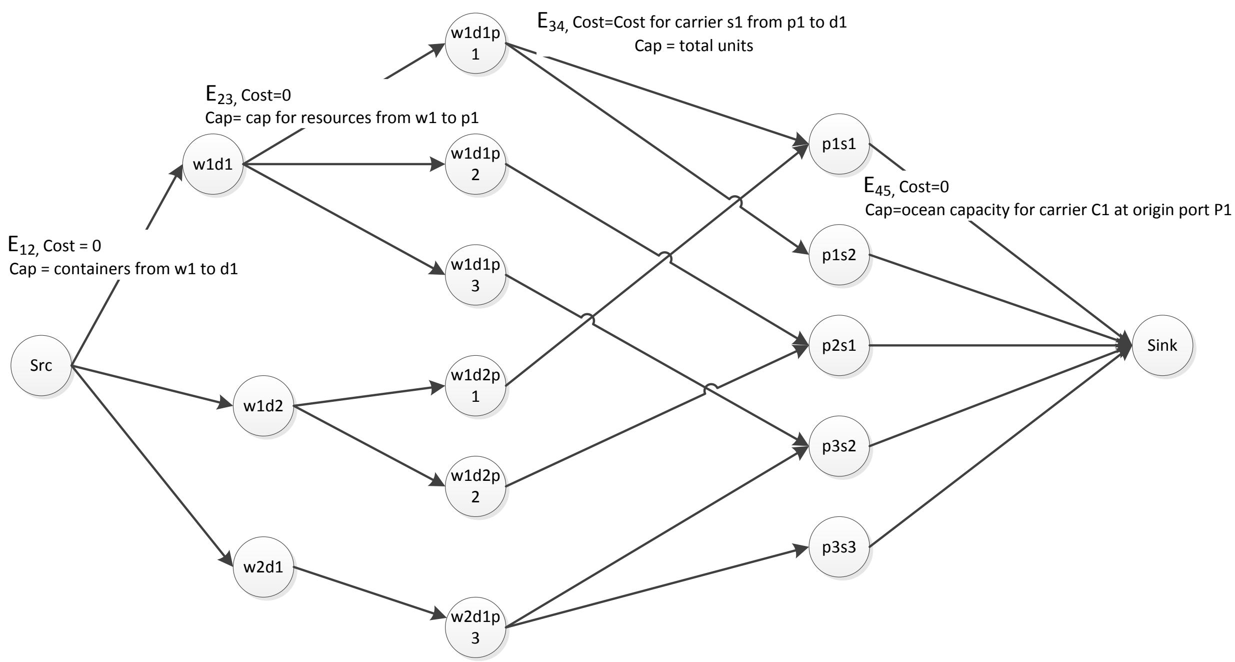

Figure 4 - Network flow model with inland locations

The enhanced flow considers the inland transportation from the warehouse to the origin port. The second level nodes represent the destination and warehouse(s) for orders in a container. If the container has a single order or multiple orders with the same warehouse then a node representing the destination and warehouse for the container is created. The capacity for the edge connecting the source node to this node is calculated as the number of containers such that all orders in these containers start at the warehouse and need to be transported to the destination. If the container has multiple orders from different warehouses then a node representing all the warehouses for orders in a container and destination for the container is created. Let us look at an example. Container 1 has two orders o_1 and o_2 with origin location/warehouses w_1 and w_2 and destination d_1. Container 2 has two orders o_3 and o_4 with origin location/warehouses w_1 and w_2 and destination d_1. Container 3 has two orders o_5 and o_6 with origin location/warehouses w_2 and w_3 and destination d_1. A node will be created to represent $w_1w_2d_1$ and the capacity of the edge connecting the source node to this node would be 2 as there are two containers with orders starting at w_1 and w_2. Another node $w_2w_3d_1$ will be created and the edge capacity from source node to this node would be 1. Nodes will be created for warehouse(s) and destination combination only if containers to be moved have order(s) from warehouse(s) to the destination.

A Level 3 node is added for each origin port if inland transportation is available from warehouse (s) represented in level 2 node to the origin port. This limits the origin port selection, compared with the earlier network flow model, for shipping containers. Now a container may be shipped only to those origin ports that have inland transportation from the warehouse (s) for all orders in the container.

The next three levels are similar to the levels in the network flow in Figure 3 and represent origin ports that service destination port such that inland transportation is available, ocean resource cost and port capacity.

Let the set of warehouses/inland locations be W. Formally the set of vertices, edges and cost and capacity at each level are defined as

$V_1 = \{src\}$

$V_2 = \{w_1 w_{2..} w_i d \mid w1, w2, .. wi \in W, d \in D$, *for some container there is order consolidation from warehouses* $w_1, w_2 .. w_i$ *and container's destination is d\}*

$V_3 = \{vp \mid v \in V_2,\ p \in P, where\ \ v = \ w_1 w_2 .. w_k d\ \ and\ for\ each\ w_i, 1 \leq i \leq k,$

$there\ exists\ t\ \in\ T\ such\ that\ w_i = origin(t)\ and\ p = destination(t)\ \ and\ there\ exists$

$c \in C$ *such that origin (c)=p and destination (c)=d*

$V_4 = \{sp \mid s \in S, p \in P$, *carrier (c) = s and origin (c) = p for some* $c \in C\}$

$V_5 = \{sink\}$

The set of edges connecting level one node to level two nodes is defined as $E_{12} = \{(src, v) \mid v \in V_2\}$. For edge (u, v) ∈ E_{12}, cost is zero and capacity is the number of containers with orders from warehouse(s) $w_1 w_{2..} w_i$ that need to be moved to destination d, note $v = w_1 w_2 .. w_i d$.

cost (u, v) = 0, (u, v) $\in E_{12}$

capacity (u, v) = number of containers with orders from warehouses $w_1 w_{2..} w_i$ *and to destination d, (u, v)* $\in E_{12}, v = w_1 w_2 .. w_i d$

The set of edges connecting level two nodes to level three nodes is $E_{23} = \{(v,vp) \mid v \in V_2, vp \in V_3\}$. For all resources with size greater than or equal to the container size calculate the sum of resource size. Let this value be sum_1. These resources can move one or more containers. For resources with size less than container size, multiple of these resources are required to move a single container. The number of resources required to move a container is calculated by dividing the container size by resource size and rounding up to the nearest integer.

An example is, the size of truck resource is 0.66 units and container is 1. 1/0.66 = 1.5 which when rounded up to the nearest integer value becomes 2. Dividing the number of such resources by the number of resources required to move a single container gives us the number of containers that can be moved. Let this value be sum_2. So if 10 trucks are available from w_1 to $p_{1,}$ then divide 10 by 2. Calculate the capacity as $sum_1 + sum_2$. When multiple nodes in level 2 represent the same warehouse either by itself (w_1d_1) or in combination with other warehouse ($w_1w_2d_1$) then the certain number of resources are reserved for each of these nodes depending on the number of containers to be moved. To illustrate, let us consider two nodes (w_1d_1) and ($w_1w_2d_1$). Number of containers with orders from w_1 to d_1 is 5 and number of containers with multiple orders from two different warehouse w_1 and w_2 going to destination d_1 is 3. Let p_1 and p_2 be two ports. There are 5 resources from w_1 to p_1 and 3 resources from w_1 to p_2. Say we reserve 3 resources from w_1 to p_1 and 2 resources from w_1 to p_2 for node (w_1d_1), then 2 resources from w_1 to p_1 and 1 resource from w_1 to p_2 are reserved for ($w_1w_2d_1$). Both ports p_1 and p_2 service destination port d. The actual allocation also depends on the actual size of all the order from w1 and the inland resources from w2 to the respective ports. Thus this network model is a conservative network model that does not allow adjustment resources once the allocation has been done. Capacity is then calculated using these reserved resources. Let T_{wp1} be the set of reserved resources from warehouse w to origin port p with resource size greater than container size and T_{wp2} be the set of reserved resources from warehouse w and origin port p with resource size less than container size. Formally they are defined below:

$cost\ (u, v) = 0, (u, v) \in E_{23}$

$capacity(u, v) = \sum_{t \in T_{wp1}} size(t) + (T_{wp2}/(1/size(r))), \quad (u,v) \in E_{23}, \ r \in T_{wp2}, \ u=wd, v=wdp.$

The next set of edges E_{34} = {(u, v) | u$\in V_3, v \in V_4$, origin(c) = p and destination(c)=d and carrier(c) = s for some $c \in C$, *where v=sp and u=*$w_1 w_2 .. w_i dp$} represent the ocean transportation cost.

cost (u, v) = cost(c), (u, v) $\in E_{34}$, , origin(c) = p and destination(c)=d and carrier(c) = s for some $c \in C$, *where v=sp and u=*$w_1 w_2 .. w_i dp$

capacity (u, v) = $total\ number\ of\ containers\ avaliable\ to\ be\ moved\ from\ p\ to\ d\ by\ carrier\ s,$ *(u, v)* $\in E_{34}$

Finally, E_{45} = {(u, sink) | u$\in V_4$} set of edges connecting level four nodes to sink node represent the port capacity,

cost (u, sink) = 0, (u, sink) $\in E_{45}$

capacity (u, sink) = w_{ij}*, (u, sink)* $\in E_{45}, u = s_i p_j,\ 1 \le i \le S, 1 \le j \le P$

Thus if a minimum cost maximum flow is found for this network then there always exists an inland transportation solution to move the orders from the warehouses to the ports determined by the flow solution.

Based on the order assignment to ocean container resources and the origin port selection in the network flow steps, origin of the order becomes the origin and the origin port becomes the destination for the inland transportation leg. Several inland transportation resources are available at inland/warehouse locations. Each inland transportation resource has a known cost, potentially a different size and a different inland carrier that operates it. The problem at hand is to transport all the orders from the inland/warehouse location to the origin ports determined in the previous step by assigning the orders to one or more inland transportation resources while minimizing cost for all selected resources. Assumption 2 states that the inland transportation resource starts at an origin location and ends at the origin port. Orders with the same origin location and same origin port are grouped into subsets of orders. The inland carrier selection with consolidation for every subset of orders is formulated as a variable sized bin packing with costs problem. O is the subset of orders with sizes size(o_1), size(o_2)..size($o_{n'}$) ≤ 1. Inland transportation resources are t_1, $t_2 \ldots t$ with sizes size(t_1), size(t_2)…size($t_{m'}$) and costs cost(t_1), cost(t_2)…cost($t_{m'}$). y_j = 1 if inland transportation resource t_j is utilized. x_{ij} = 1 if order o_i is assigned to inland transportation resource t_j.

min $\sum_{j=1}^{m'} y_j * cost(t_j)$

Such that $\sum_{i=1}^{n'} size(o_i) * x_{ij} \leq size(B_j) * y_j, \forall j \in \{1,2..m'\}$ (1)

$\sum_{j=1}^{m'} x_{ij} = 1, \forall i \in \{1,2..n'\}$ (2)

$y_j \in \{0,1\}, \forall j \in \{1,2..m'\}$ (3)

$x_{ij} \in \{0,1\}, \forall i \in \{1,2..n'\} \forall j \in \{1,2..m'$ (4)

The objective function minimizes the total cost of all selected inland transportation resources. Constraint (1) makes sure that the total size of all the orders assigned to the inland transportation resource does not exceed the size of the inland transportation resource. Constraint (2) ensures that every order is only assigned to one inland transportation resource. (3) and (4) enforce integrality requirements on decision variables. The first-fit decreasing algorithm [20] for classic bin packing is used in the prototype to solve the order consolidation problem, which is modeled as the classic bin packing problem. The inland transpotion, which is modeled as the variable-sized bin packing with cost above, is solved by a proposed heuristics algorithm.

Solving the three sub problems returns a near optimal solution for the export intermodal transportation problem.

3.6 Backtracking Approach

To baseline the optimal solution, backtracking approach is applied to the export intermodal transportation problem and a prototype is created.

As per the assumption 2 every order has one inland transportation leg and one ocean transportation leg. Figure 5 depicts a tree structure for an instance, of export intermodal transportation problem. In the tree structure every order is represented with two levels, one for inland transportation leg and one for ocean transportation leg.

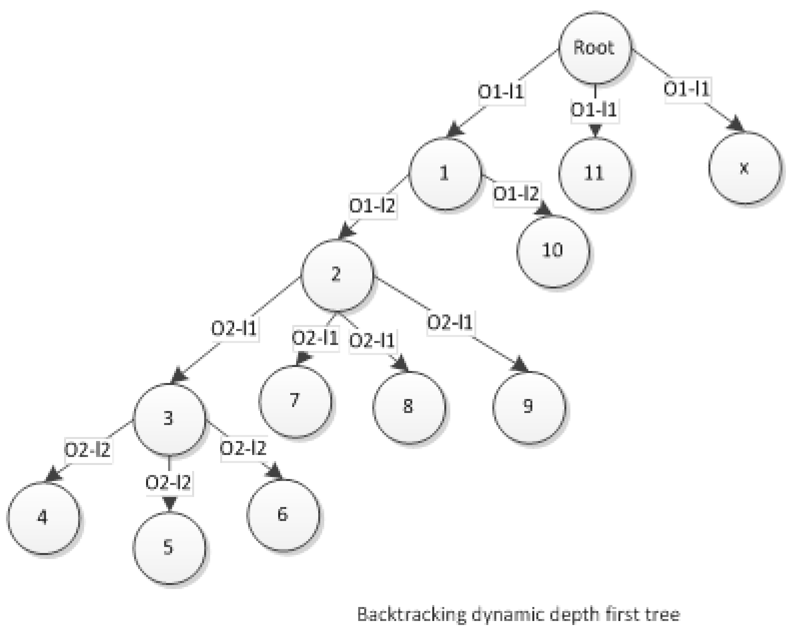

Figure 5 - Backtracking model

The set of orders is defined in the formulation as $O=\{o_i \mid 1 \leq i \leq n\}$. T and C represent the sets of inland and ocean resources respectively. The depth of the tree for backtracking is 2n. The number of child nodes at odd levels (1, 3.. 2n-1) is bounded by the set of inland transportation resources $T_i \subseteq T$ for order o_i. In addition to size, free space attribute is calculated for each inland resource. For example if an inland resource of jumbo railcar was chosen in level 1 for an order of size 1 unit then the same jumbo railcar is available at level 3 with free space of 2. Similarly if it was chosen for an order of size 1 unit in level 3 then it is available at level 5 with free space 1. Formally,

$T_i = \{t_j \mid 1 \le j \le m, origin(t_j)=origin(o_i) \text{ and } freespace(t_j) \ge size(o_i)\}, for \forall\, o_i,\ 1 \le i \le n$

The number of child nodes at even level (2, 4..2n) is bounded by the set of ocean container resources $C_i \subseteq C$ for order o_i and inland resource t_j representing the previous level node. Formally,

$C_i = \{cl \mid 1 \le l \le k, destination(c_l)=destination(o_i) \text{ and } freespace(c_l) \ge size(o_i) \text{ and } origin(c_l)=destination(t_j)\}, for\ \forall\, o_i \in O \text{ and } t_j \in T_i$

The path from the root node to a leaf node is a feasible solution for the export intermodal transportation problem. A feasible solution with minimum cost is the optimal solution.

A root node is created. An unordered list of orders is used. Odd level nodes are created for inland transportation resources for the order and even level nodes are created for ocean container resources. Free space is adjusted for inland and ocean resources as the computation traverses through various paths. When the computation progresses in the levels it decreases the free space by order size and when it backtracks it increases the free space by order size. The prototype keeps track of the least cost leaf node for the least cost solution at every stage of the computation as it finds feasible solutions. If a feasible solution is found with cost less than the least cost found so far then it replaces the least cost found so far and updates the leaf node. The least cost found so far is also used as a bounding function. If at any level the cost of the path is greater than the least cost then the computation backtracks. For example, if at level x the cost of path from root node to that node is greater than the least cost then the computation backtracks to level x-1. The reason being that if the cost so far is greater than the least cost then traversing to any nodes in the sub-tree under that node would have cost greater than the least cost.

An upper bound of the size of solution space is defined below:

Total number of nodes = ((upper limit on inland options for any order) x (upper limit on ocean options for any order)) ^ number of orders

The size of solution space and runtime exponentially increase with the number of orders. The backtracking approach returns order assignment to inland and ocean resources. Multiple orders assigned to the same resource indicate consolidation.

4. PROTOTYPE

This chapter describes architecture for the prototype, algorithms used and prototype issues.

4.1 Architecture

A laptop computer with Windows 7 operating system and 4 GB memory was used for development and testing of the prototype. All the algorithms are prototyped in Java 1.6 due to the familiarity of the programming language. An opensource integrated development environment (IDE) called Eclipse is used for Java development and prototype testing.

The input and output data is stored in database tables versus using flat files or excel spreadsheets as it is easier to write SQL statements to query for specific information than to perform a search on the files. For the database server, Microsoft SQL Server Express 2012 is used which is a free edition of SQL Server that offers 10 GB of storage per database. The input data is loaded into the tables using excel spreadsheets or delimited text files.

The database structures used in the prototype are defined below.

4.1.1 Orders table

This database table is used to store the order information. Start and end date are not used at this time but would be used when solving the problem with time windows.

ORDERNO	ORIGIN	DESTINATION	SIZE	START_DATE	END_DATE
OA1	W2	D12	1	NULL	NULL
OA2	W5	D12	1	NULL	NULL
OA3	W2	D12	1	NULL	NULL
OA4	W5	D22	1	NULL	NULL
OA5	W5	D12	1	NULL	NULL

OA6	W5	D22	0.66	NULL	NULL
OA7	W2	D12	1	NULL	NULL
OA8	W5	D30	1	NULL	NULL
OA9	W5	D12	1	NULL	NULL

4.1.2 Inland Transportation Resource Table

This database table is used for storing inland transportation resources. The inland transportation resource starts at the inland location (warehouse) and ends at the origin port. Mode is used for informational purposes. Transit, start date and end date would be used when solving the problems with time zone. If an inland transportation resource has a schedule then start and end dates would be used. If the inland transportation resource can start at any time then transit is used to capture the duration from warehouse to origin port. In this case the start and end dates are calculated by defaulting the start date to the start date of the order that is assigned to the resource and end date is calculated by adding transit to the start date.

WAREHOUSE	ORIGIN PORT	MODE	CARRIER	COST	SIZE	TRANSIT	START DATE	END DATE
W5	P1	Jumbo Rail	R1	245	3	NULL	NULL	NULL
W5	P2	Jumbo Rail	R1	246	3	NULL	NULL	NULL
W5	P7	Jumbo Rail	R1	246	3	NULL	NULL	NULL
W5	P1	Std Rail	R1	179	2	NULL	NULL	NULL
W5	P7	Truck	T1	179	0.66	NULL	NULL	NULL
W5	P9	Truck	T1	45	0.66	NULL	NULL	NULL
W5	P10	Truck	T1	60	0.66	NULL	NULL	NULL
W1	P5	Src Loaded Cnt	SC1	11	1	NULL	NULL	NULL
W8	P5	Src Loaded Cnt	SC1	28	1	NULL	NULL	NULL

4.1.3 Ocean container resource table

This database table stores the ocean container resources with origin port, destination port, ocean carrier and cost. Start and end date would be used when solving the problem with time zones.

ORIGINPORT	DESTPORT	CARRIER	COST	START_DATE	END_DATE
P3	D5	C8	162	NULL	NULL
P4	D5	C7	158	NULL	NULL
P10	D32	C2	197	NULL	NULL
P10	D32	C5	202	NULL	NULL
P10	D10	C5	167	NULL	NULL
P10	D30	C1	240	NULL	NULL
P10	D30	C4	177	NULL	NULL
P10	D22	C1	229	NULL	NULL
P10	D22	C7	164	NULL	NULL

4.1.4 Ocean carrier and origin port resource limit table

Ocean container resources are limited by ocean carrier and origin port and are stored in this table.

ORIGINPORT	CARRIER	NUMBER OF RESOURCES
P7	C1	60
P2	C1	60
P5	C2	60
P7	C2	60
P8	C2	60
P2	C2	60
P1	C3	60
P7	C3	60
P2	C3	60

4.1.5 Solution tables

The table below saves the ocean transportation solution for orders. Same resource number for two orders indicates that orders are consolidated on the same ocean container resource. The sum of cost of distinct resource numbers gives the total cost for ocean transportation.

RESOURCE NUMBER	ORIGIN PORT	DESTINATION PORT	CARRIER	COST	ORDERNO	WAREHOUSE
OCN69	P1	D12	C11	76	OA44	W5
OCN70	P1	D12	C11	76	OA31	W5
OCN71	P8	D12	C7	90	OA38	W2
OCN72	P8	D12	C7	90	OA39	W2
OCN73	P6	D12	C5	101	OA61	W11
OCN74	P8	D12	C7	90	OA57	W2
OCN75	P8	D12	C7	90	OA55	W2
OCN76	P1	D12	C11	76	OA72	W5
OCN77	P8	D12	C7	90	OA69	W2
OCN78	P1	D12	C11	76	OA70	W5

The table below saves the inland transportation solution for orders. Same resource number for two orders indicates that orders are consolidated on the same inland transportation resource. The sum of cost of distinct resource numbers gives the total cost for inland transportation.

RESOURCE NUMBER	WAREHOUSE	ORIGIN PORT	MODE	CARRIER	COST	ORDERNO
INL924	W5	P1	Jumbo Rail	R1	245	OA115
INL923	W5	P1	Jumbo Rail	R1	245	OA116
INL923	W5	P1	Jumbo Rail	R1	245	OA113
INL925	W5	P1	Std Rail	R1	179	OA110
INL924	W5	P1	Jumbo Rail	R1	245	OA107
INL924	W5	P1	Jumbo Rail	R1	245	OA6
INL101	W5	P2	Std Rail	R1	184	OA183
INL101	W5	P2	Std Rail	R1	184	OA178
INL111	W5	P8	Src Loaded Cnt	SC1	108	OA19
INL112	W5	P8	Src Loaded Cnt	SC1	108	OA32

4.2 Algorithms

This section describes the algorithms used for prototyping the solution approach and the backtracking approach.

4.2.1 Bin packing first-fit decreasing algorithm

Orders are first divided into different sets based on destination port of the order. The number of sets of orders is equal to the number of distinct destination ports across all orders. The bin packing first-fit decreasing algorithm is then applied to every set of orders. All the orders within a set are sorted in non-increasing order. The algorithm loops through the sorted orders and finds a resource for every order. It first checks if there is an existing resource such that the order will fit, if found the order is assigned to that resource, if not found then a new resource is created. The algorithm returns total number of resources and assignment of orders to each resource. All the attributes of the ocean transportation resource are not determined at this time. Some of the attributes like carrier, origin port etc are determined after the minimum cost maximum flow algorithm is run.

<u>Psuedo Code</u>

```
For each order o in nonincreasing size do
      For each used resource r in chronological order being first used do
            If o fits in r then
                  Assign o to r
                  Break
      If no used resource can be used to fit o then
            Make a new resource as used and assign o to it
```

4.2.2 Cycle Cancelling Algorithm for Minimum Cost Maximum Flow [22]

The Cycle Cancelling Algorithm is used to find the minimum cost maximum flow. The first step in the minimum cost maximum flow algorithm is to find a maximum flow. There could be multiple maximum flows in a network model; any one of those maximum flows is used as the feasible flow in first step. In this study the relabel-to-front algorithm [21] was implemented for finding the maximum flow. The network model is a directed graph G = (V, E). Every edge (u, v) in the network model have two attributes: cost (u, v) and capacity (u, v). A flow for edge (u,v) is given by f (u,v). A reverse edge (v,u) is introduced in the graph for every edge (u,v) with the following properties: f(u,v) = -f(v,u), cost(u,v) = -cost(v,u). Thus some negative cycles could exist in the flow after the maximum flow algorithm is run. Eliminate all negative cycles by adjusting the flow. Bellman-ford algorithm [23] is implemented to detect the negative cycle and then the flow is pushed to eliminate the negative cycle.

At the end of the cycle cancelling algorithm the implementation loops through all the arcs and transforms the data from the network flow into ocean container resource with origin port, destination port and ocean carrier selection and applies it to the appropriate order. The results are stored in a database table.

4.2.3 Variable Sized Bin Packing with Heuristics Algorithm

As there are several inland transportation resources with different sizes available for inland transportation the simple single sized bin packing algorithm cannot be applied here. Orders are divided into different sets based on origin location which is the inland/warehouse location and origin port which becomes the destination for the inland leg of transportation. All orders in a set have the same origin warehouse and the same origin port. The variable bin packing with heuristics is applied once for every set of orders. Every inland transportation resource matching in origin and destination is selected. Every order represents an item and every resource represents a bin in the variable size bin packing with costs formulation.

The items are sorted in non-increasing order of size and bins are sorted in non-decreasing order of cost per unit size. A variable called unassigned quantity is calculated as the sum of size of all items not assigned to any bin. This value is used when selecting a new resource.

First, the prototype loops through existing bins to accommodate the item. This prototype does not use any heuristic to select an existing bin but traverses through them sequentially. If such a bin is found then the item is packed in that bin and unassigned quantity is reduced by the size of the item. If an existing bin was not found then, the prototype loops through the remaining orders such that the order is not already packed to check if any of those can be packed in the existing bins. This step is important for proper adjustment of unassigned quantity. To illustrate this lets look at an example with 4 items i_1, i_2, i_3 and i_4 with sizes 0.66, 0.66, 0.2, 0.1. Let 4 bins b_1, b_2, b_3 and b_4 with sizes 1, 1, 0.66, 0.66 be available with cost 5, 5, 3.5, 3.5 respectively. The cost per unit for b_1, b_2 is 5. The cost per unit for b_3 and b_4 is 3.5/0.66=5.3. Item i_1 is packed in bin b_1. The unassigned quantity is adjusted to 0.96. Item i_2 cannot be packed in bin b_1. If a new bin is selected at this time using the unassigned quantity value of 0.96 then it would be bin b_2. Thus the total cost would be 10. Instead if the prototype loops through all the items to adjust the unassigned quantity then items i_3 and i_4 would be packed into bin b_1. Thus the unassigned quantity is only 0.66. Selecting b_2 though cheaper based on cost per unit, adds more absolute cost when unassigned quantity is 0.66. Thus bin b_3 would be selected and the total cost would be 8.5.

If the item could not be packed in an existing bin then a new bin is created.

To select a new bin, the prototype uses a heuristics. It first finds a bin with minimum cost per unit that is big enough to accommodate the item and has size less than or equal to the unassigned quantity. If such a bin is found then the item is packed in it. If no such bin is found then the implementation finds a least cost bin that can fit the order. The size of this bin is greater than the unassigned quantity. If such a bin is found then the item is packed in it. If no such bin is found then the implementation cannot find a feasible solution. The unassigned quantity is adjusted by subtracting the item size anytime the item is packed in a bin.

<u>Psuedo Code</u>

```
unassignedqty = sum of sizes of all items.

For each item i in nonincreasing size do

        For each used bin k in chronological order being first used do

                if item i has not packed to a bin and fits in bin k then
                        pack item i in bin k
                        unassignedqty = unassignedqty – size of item i
                        break
                else
                        for each unpacked item j
                                if item j fits in bin k then
                                pack item j in bin k
                                unassignedqty = unassignedqty – size of item j
                                end if
                end if
        if item i did not fit in an existing bin then
            find a bin among the not used bins with minimum cost per unit  that satisfies bin size
            ≥ item size and bin size ≤ unassigned qty
                if such a bin is found then
                        pack the item in it
                else
                        find the bin with minimum value z* such that bin size ≥ item size and bin
            size ≥ unassigned qty
                        if such a bin is found then
                                pack the pack all the remaining item in it
                        else
                                no solution can be found
```

end if
end for
z is calculated as (cost of bin/unassigned qty)

This variable sized bin packing algorithm when applied to the inland transportation problem returns the list of inland resources for each order set and the order consolidation in each resource. Every resource has a cost and carrier associated. The total cost of the inland solution is the sum of costs for all resources that at least have one order assigned.

Using the three algorithms described above a near optimal solution is achieved for the export intermodal transportation problem. To baseline the optimal solution and compare the results of the above approach a backtracking approach is prototyped.

4.2.4 Backtracking

The backtracking prototype follows the backtracking model presented in chapter 3.

4.3 Backtracking Prototype Issues

Program runtime was the biggest hurdle faced during prototyping and testing. In the initial prototyping no results were stored until the program run was complete and a least cost solution was found. This was changed to store the first feasible solution found and then to overwrite with every improvement found after that. In some instances the program ran for 24 hours and still did not complete but the best solution found until that point was stored in the result tables.

5. RESULTS AND ANALYSIS

The input data was provided by a Fortune 500 food company and is real business data. However a transformation was applied to the data to maintain confidentiality. Most of the orders in the data sets used happened to be 1 unit size and did not require order consolidation on ocean containers.

5.1 Overall Cost Comparison

Test #	Backtracking	Three stage solution approach	Manual Planning
Test 1	4115	4162	4230
Test 2	21899	21704	22952
Test 3	14811	14951	15052
Test 4	31182	30758	32682
Test 5	30304	30085	30210

On an average, the three stage solution approach reduced the overall cost by 3.3% as compared to manual planning. When compared against backtracking results captured after running the program for 30 minutes, the solution cost of three stage solution approach was less than backtracking approach for 60% of the tests.

5.2 Ocean Cost Comparison

Test #	Backtracking	Three stage solution approach	Manual Planning
Test 1	2076	2076	2133
Test 2	13836	13481	14684
Test 3	9748	9830	9974
Test 4	17857	17195	18036
Test 5	18232	17562	17745

The ocean cost calculated by three stage solution approach is better than ocean cost by the backtracking in 80% of the tests.

5.3 Inland Cost Comparison

Test #	Backtracking	Three stage solution approach	Manual Planning
Test 1	2039	2086	2097
Test 2	8063	8223	8268
Test 3	5063	5121	5078
Test 4	13325	13563	14646
Test 5	12072	12523	12465

The backtracking approach returned better results for the inland transportation for 100% of the tests. In the three stage solution approach, the minimum cost maximum flow makes sure that inland transportation is available to the origin port when selecting the origin port and ocean carrier. It does not take into account the cost of inland transportation. In the future the network flow should be enhanced by adding average costs for inland transportation from warehouse to origin port.

5.4 Runtime Comparisons

Test #	**|O|**	**|T|**	**|C|**	**|P|**	**|S|**	**|D|**	**Backtracking**	**Three Stage Solution**
Test 1	25	100	95	7	11	6	30 min*	312 ms
Test 2	105	3120	5040	6	11	16	30 min*	998 ms
Test 3	66	2310	2820	7	11	13	30 min*	1310 ms
Test 4	179	7650	9810	10	11	20	30 min*	2355 ms
Test 5	159	8640	11880	11	11	21	30 min*	1217 ms

where

|O| - size of set of orders

|T| - size of set of inland transportation resources

|C| - size of set of ocean container resources

|P| - size of set of origin ports

|S| - size of set of ocean carriers

|D| - size of set of destinations

ms – milliseconds

min – minutes

*indicates that the program did not complete and was terminated after 30 minutes.

When the maximum number of inland transportation resources and ocean container resources available for a single order was 5 or less, the backtracking program found the optimal solution. When the maximum number of inland transportation resources and ocean container resources available for a single order was greater than 5, the backtracking program did not complete in 24 hours and had to be terminated.

6. CONCLUSION AND FUTURE WORK

6.1 Summary

This study was conducted with the intention of formulating the export intermodal transportation problem and finding the optimal or near optimal solution in polynomial time. The solution approach used bin packing, minimum cost maximum flow and variable sized bin packing with fixed costs algorithms.

The three stage soltion approach prototype reduced the overall cost by an average of 3.3% and backtracking prototype reduced the overall cost by an average of 2.8% when compared to the manual planning solution. The three stage solution approach runtime took milliseconds and it returned better results than the backtracking approach for 60% of the tests.

When the maximum number of inland transportation resources and ocean container resources available for a single order was 5 or less, then the backtracking program found the optimal solution. When the maximum number of inland transportation resources and ocean container resources available for a single order was greater than 5, the backtracking program did not complete in 24 hours and had to be terminated.

6.2 Future Work

The prototype assumed a single ocean container size but can be easily extended to multiple ocean container resource sizes by using variable sized bin packing instead of classic bin packing. The network flow model does not represent inland transportation costs. This model can be enhanced to include average inland costs which could reduce inland transportation costs for the three stage solution approach.

In this study, the time window constraint was relaxed. Time windows are important in real world logistics applications. The backtracking approach was prototyped with time constraints. More research is required to incorporate the time constraints in the three stage solution approach. The solution approach currently considers the maximum number of resources but does not consider the minimum quantity commitments (MQC). The network flow can be enhanced to include minimum and maximum flow limits on the arc. More research is required to include MQC in the variable sized bin packing for inland transportation. Some heuristics can be developed to influence the new bin selection based on MQC value. Currently only a single bounding function is used in the backtracking prototype. Additional work is required to identify the bounding functions that could improve backtracking prototype runtime.

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