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Review Article

An Intercontinental Multi-Modal Distribution Model for Containerized Goods

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Abstract

Technological advancement, communication facilities and easy of Internet access have made it possible for manufacturers, entrepreneurs, and distributers to have their operations on a global scale, manufacture goods at one continent and ship them to customers and end-users to other continents. They utilize low labor costs, easy-available land and utilities, and transportation facilities to minimize manufacturing and transportation costs, and increase their bottom line. Goods and services worth two trillion dollars, on an average, cross international borders every single day. Industrial distribution is a four trillion dollar business. This paper describes an intercontinental shipping scenario that necessitates multi-modal transportation systems for distribution of goods. Ships are used between ports of two or more continents, and trucks or railroads are used to transport goods from inland plant locations (sources) to the source-continent seaports and also from the destination-continent seaports to the inland demand points. This is atypical scenario of intercontinental shipping or distribution that is accomplished by using multi-modal transportation system. A mixed integer mathematical programming model is formulated that minimizes the fixed and variable costs from sources to final destinations. The mathematical model is further transformed to a Microsoft Excel model. Several problems are solved by using SOLVER that yielded an optimal solution. Distribution or logistics companies that have intercontinental operations can easily utilize this model and printout their cargo allocations to various available alternatives and thus become competitive in transporting their industrial products across continents. Intercontinental distribution is a multi-trillion dollar business and even a mere five percent saving in distribution/shipping costs will amount to hundreds of millions of dollars annually.

Keywords: Mixed integer mathematical programming model; Intercontinental distribution; Multi-modal transportation systems

Introduction

Goods and services worth two trillion dollars cross international borders every single day, on an average. Multi-national corporations select their plant sites after considering various factors, such as political, economical, financial, labor environments, etc. so that goods are produced at a minimum cost. However, the transportation cost, from the manufacturing site to the end-consumer also has a significant impact on the competitiveness. For example, China not only manufactures industrial goods at a low cost by utilizing its inexpensive labor force, space, and overheads, but also utilizes large ships for distributing its goods to other continents while employing Chinese crew to minimize the transportation cost.

Most large corporations operate globally and utilize various factors to their advantage in order to remain competitive. Their global operations require efficient and effective distribution processes to achieve or remain competitive. For example, large oil and gas companies have acquired exploration rights in the Caspian Sea and its surrounding areas of Kazakhstan, as it has a huge reserve of oil and gas. They utilize multi-modal transportation system for distributing their products that includes pipelines, railroads, trucks, airplanes, and ships. Even though several thousand miles of pipelines have been laid to supply gas and crude oil from the Caspian sea basin, to Russia, Europe, and china, international shipping still dominate the transportation arena for intercontinental distribution of industrial goods.

This paper describes an intercontinental shipping scenario that necessitates multi-modal transportation system for distribution of goods. Ships are used between ports of two or more continents, and trucks or railroads are used to transport goods from inland plant locations (source) to the source continent seaports and also from the destination continent seaport to the inland demand points.

A mixed integer programming model is formulated that minimizes the fixed and variable costs from sources to final destinations. This model will help distribution or logistics companies become or remain competitive in transporting their industrial products across continents by utilizing multi-modal transport systems.

Industrial distribution is a four-trillion dollar business that includes transporting goods from manufacturers to end-consumers, maintaining inventories, providing credits, technical product support, sales and service. Even a mere five percent saving in distribution cost amounts to two-hundred billion dollars annually, a colossal amount. This model can be utilized any companies that have intercontinental

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Figure 1: A Map Showing an Intercontinental shipping Scenario and Multi-modal Transportation.

operations or utilize multi-modal transportation system.

Literature Review

Lyridis et al. [1] describe and suggest optimizing shipping company operations using process modeling. They built process models of various port operations and functions, including shipping of cargo units, at different levels using a hierarchical approach. They further apply their approach to a real-world scenario of a European shipping line.

Mondragon et al. [2] describe the importance of Information and Communication Technology (ICT) to improve the level of visibility, responsiveness, and efficiency in supply chain relying in multimodal transport operations and emphasize that with the use of wireless vehicular networks, Intelligent Transport Systems (ITS) have the potential to shape the future of multimodal logistics. They further investigate the role of vehicular networks play in handling bulk material transported by sea that is further unloaded into haulage vehicles.

Rana and Vickson [3] describe a ship chartering scenario, develop a ship scheduling model to evaluate various ships available for chartering and make informed decisions based on profits accruing from each vessel. Rana and Vickson [4] further develop a large mixed integer non-linear programming model, decompose it into several linear sub-problems and solve it by Lagrange an relaxation. Rana [5] also developed a solution technique to solve mixed integer linear problems and exemplified it with aircraft scheduling problems. Rana [6] describe maritime operations, the importance of containerization, and developed a complex ship routing and scheduling mathematical programming model that can be used by a shipping company operating several ships.

Ronen [7] conducted a survey of cargo ship routing and scheduling models formulated and published until 1982. Sun and Tan [8] modeled a probability distribution of cargo throughput. According to them, gross cargo throughput is a function of time spent by cargo ships at a port and the operating efficiency of the cargo handling equipment. Since cargo ships spend different times at a port depending upon the size of the cargo, it leads to the variability of the gross cargo throughput.

Xiang [9] determine the most critical factors that impact a port throughput and utilized a method factor analysis for forecasting port throughput. He selected indicators that influence the cargo throughput, including GDP, population, output values of the primary, secondary, and tertiary industries, rail freight, highway freight, total import and export, total freight, etc.

Karloftis, Kepaptsoglou and Sambracos [10] present a containership routing problem with time deadlines, whereas Kobayashi and Kubo [11] optimize oil tanker schedules by decomposition. Hennig et al. [12] address a crude oil transportation-split pickup and delivery problem. Gunnarsson, Ronnqvist, and Carlsson [13] formulate a combined terminal location and ship routing problem. Fagerholt, Korsvik, and Lokketangen [14] discuss ship routing and scheduling with persistence and distance objectives, whereas Chuang et al. [15] use fuzzy generic algorithm for planning liner shipping. Bredstrom, Carlsson, and Ronnqvist [16] use a hybrid algorithm for distribution problems. Bronmo, Christiansen, and Nygreen [17] describe a planning problem in tramp-shipping industry. Their objective is to maximize profit using flexible cargo sizes instead of fixed sizes. Christiansen et al. [18] study and conduct a survey of ship routing and scheduling problems during the last decade and divide them into four categories. Lieu [19] present an inter-modal transportation model for a coal distribution problem. However, complex critical problems remain wide open and provide challenging opportunities for future research. Intercontinental distribution problems are quite complex as well challenging and we address one such problem in this paper.

An Intercontinental Distribution Scenario

In this age of information and technological advancement, communication facilities and easy Internet access have made it possible for manufacturers, entrepreneurs, and distributers to have their operations on a global scale, manufacture goods at one continent and ship them to customers and end-users of other continents. They utilize low labor costs, easy-available land and utilities, and transportation facilities to minimize the cost of manufacturing and transportation, and increase their bottom line. They can take advantage of the economy of scale and economy of scope by building large facilities at a few locations. In business operations, mainly

Source	Available Cargo, No. of containers	Seaport J capacity	Requirements	Destination	Requirements
1	5000	1	60000	1	6000
2	6000	2	70000	2	5000
3	7000	3	50000	3	7000

	Cost matrix from sources to ports			Costs from sources to seaports	Fixed cost	Binary variables
	1	2	3			
1	50	60	70		100	1
2	60	55	80		150	1
3	70	80	45	570	200	1
				450		
Fixed cost	200	300	250	750	Binary Variables need to be 1	
Binary variables	1	1	1	1770	Total	
Seaport capacity at source continent	60000	40000	30000	Fixed cost plus land transportation cost		

	Number of containers shipped			Total shipped	Sign	RHS
	1	2	3			
1	1	1	1	3	≥	0
2	1	1	1	3	≥	0
3	1	1	1	3	≥	0
Total received	3	3	3			
Sign	≤	≤	≤			
	60000	40000	30000			

	Cost matrix for port to port			Costs from continent to continent	Fixed cost	Binary variables
	1	2	3			
1	50	60	70		300	1
2	60	55	80		350	1
3	70	80	45	570	400	1
				1050		
Binary variables	1	1	1	1150		
Fixed	400	300	450	2770	Total	

Figure 2: An Excel worksheet with initial parameters.

three items move between a supplier and a buyer, namely: goods, information, and cash. Information and cash can easily transmitted by using Internet facilities, wire transaction, etc. However, goods need to move physically from the supply to the customer.

This paper deals with such a scenario. Suppose an ABC company has a manufacturing facility in Midwest states, like Kansas, Missouri, Oklahoma, Arkansas, etc. And the final destinations of manufactured goods are Almaty, Taraz, and Astana, Kazakhstan; Tashkent, Uzbekistan; and Bishkek, Kyrgyzstan. Also, the current trend is to utilize containerized shipping as it is not only convenient but also provides protection and security of goods. In this example, goods containers need to be transported by railroad or trucks to a seaport, from where they are shipped to a seaport of an Asian continent by ships, and then transported to the their final inland destinations. This is an example of intercontinental shipping or distribution that is accomplished by using multi-modal transportation system. This scenario is depicted in (Figure 1).

Mathematical Model

The scenario described in Section 3 above is formulated in this section as a mixed inter linear programming problem. This model has continuous variables and binary variables. Containers that are shipped from sources to destinations are continuous variables and whether a node of the network is used or not is represented by binary variables. There are fixed costs associated when a node of network is used in this trans-shipment problem. Ships and trucks are required to pay port charges and fees on their visits.

Variables:

Y_{Ij} = Number of containers to be shipped from an inland source i, $i \in I$, to a seaport j, $j \in J$.

Y_{jk} = Number of containers to be shipped from seaport j, $j \in J$, of the source continent to seaport k, $k \in K$, of the destination continent.

Y_{km} = Number of containers to be shipped from a seaport j to an inland destination m, $m \in M$.

X_i = 1, if source i to be used, 0 otherwise.

X_j = 1, if source seaport j to be used, 0 otherwise.

X_k = 1, if destination seaport k to be used, 0 otherwise.

X_m = 1, if destination m to be used, 0 otherwise.

Parameters:

S_i = Capacity of supply source i, $i \in I$.

D_m = Demand at destination m, $m \in M$.

C_I = A fixed cost incurred at inland source i, if containers are picked from source i.

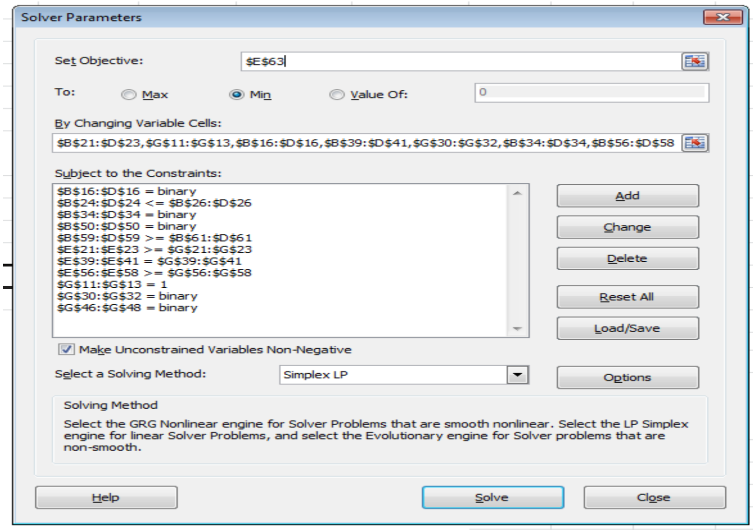

Figure 3: A Copy of the solver parameters showing variables as changing cells and constraints.

C_j = A fixed cost incurred at seaport j of the source continent, if the seaport j is to be used.

C_k = A fixed cost incurred at seaport k of the destination continent, if the seaport k is to be used.

C_m = A fixed cost incurred at destination m, if the goods are shipped to the destination.

C_{Ij}= an average variable cost per container for shipping from source i to seaport j.

C_{jk}= an average variable cost per container for shipping from source seaport j to seaport k.

C_{km}= an average variable cost per container for shipping from source i to seaport j.

In this scenario, we would like to minimize the total fixed cost and shipping cost of the entire shipment from all sources to the desired destinations. Therefore, the objective function can be stated as:

Objective Function:

Total cost, $Z = \Sigma_{I} \in _{I} C_{i} X_{i} + \Sigma_{j} \in _{J} C_{J} X_{J} + \Sigma_{K} \in _{K} C_{K} X_{K} + \Sigma_{m} \in M C_{m} X_{m} +$

$\Sigma_{i} \in _{I} \Sigma j \in J C_{ij} Y_{ij} + \Sigma_{j} \in _{J} \Sigma_{K} \in _{k} C_{jk} Y_{jk} + \Sigma_{k} \in _{K} \Sigma_{m} \in _{M} C_{km} Y_{km}$ (1)

Constraints:

2. Total containers shipped from each supply source are limited by its capacity.

$\Sigma_{j} \in _{J} Y_{IJ} \leq S_{I} X_{i},$ for $i \in I$. (2)

3. Total containers shipped to a source seaport from supply sources are limited by the seaport's capacity.

$\Sigma_{i} \in _{I} Y_{Ij} \leq Cap_{j} X_{j},$ for $j \in J$. (3)

4. Total containers shipped from a supply seaport to the destination seaport are limited by the capacity of the supply seaport.

$\Sigma_{k} \in _{K} Y_{jK} \leq Cap_{J} X_{J},$ for $j \in J$. (4)

5. Total containers shipped from a source sea port must be equal to the total received from sources.

$\Sigma_{K} \in _{k} Y_{jk} = \Sigma_{i} \in _{I} Y_{Ij}$ for $j \in J$ (5)

6. Total containers shipped from a supply seaport to the destination seaport are limited by the capacity of the receiving seaport.

$\Sigma_{j} \in _{J} Y_{jk} \leq Cap_{k} X_{k},$ for $k \in K$. (6)

7. Total containers shipped from a destination seaport to final destinations are limited by the capacity of the receiving seaport.

$\Sigma_{m} \in _{M} Y_{KM} \leq Cap_{K} X_{K},$ for $k \in K$. (7)

8. Total containers shipped from a destination seaport to final destinations must be equal to the total received at it.

$\Sigma_{m} \in _{M} Y_{km} = \Sigma_{j} \in _{J} Y_{jk},$ for $k \in K$ (8)

9. Total containers shipped from a destination seaports to the final destination are limited by the destination demand.

$\Sigma_{k} \in _{K} Y_{km} \leq D_{m} X_{m},$ for $m \in M$. (9)

This intercontinental distribution model has I x J + J x K + K x M continuous variables, I + J + K + M binary variables and I + 3J + 3 K + M + binary constraints. The number of nodes in the network equals to I + j + K + M. The problem size increases with the number of nodes in the network. The number of arcs equals to the number of continuous variables.

This trans-shipment model can be solved by an available commercial software package. However, the author has developed all kinds of Microsoft Excel spreadsheets for doing quantitative analysis of various kinds of problems pertaining to supply chain, logistics, operations, finance and accounting. Spreadsheet modeling helps students to understand and apply the concepts they learn in the class and saves them the time in number-crunching. This problem is also solved by using Microsoft Excel and its in-built module, SOLVER.

An Excel Spreadsheet Model

Render, Stair, and Balakrishanan [20] have further described the importance and usefulness of spreadsheet modeling approach in managerial decision making. Kros [21] emphasize the art and science of becoming an efficient and effective problem solver and communicating results to users. His textbook uses spreadsheet modeling approach for solving several kinds of decision-making problems pertaining to logistics, operations, supply chain, and inventory management.

A spreadsheet model of the trans-shipment problem is in Microsoft Excel. First, an initial worksheet needs to be created. Variables are called Changing Cells and the cell that contains the total cost function is called the Target Cell. The creation of the initial worksheet is very important and is well-thought of. After the initial worksheet is created, the relevant information from the worksheet is entered in the SOLVER. In order to keep this paper within the prescribed limits, only three sources and destinations as well as three seaports on each of the source and destination continents are used in the example problem. Nevertheless, the spreadsheet model can easily be extended to a higher number of nodes in the network. There are several advantages of a spreadsheet modeling approach. The solution obtained by using SOLVER provides the following costs separately:

1. Cost of ground transportation from sources to seaports

2. Fixed cost of transportation, tariffs, fees, etc. paid at the sources and at the seaports.

3. Shipping costs for transporting containers from the source continent to the destination continent.

4. Fixed cost paid by ships for entering/leaving ports, tariffs, fees, etc. at the source and the destination seaports.

5. Cost of ground transportation from seaports to destinations.

6. Fixed cost ground transportation at the destination continent.

We solved a problem with assumed parameters that are entered in the first fifteen rows of the initial worksheet. After the parameters are entered, the following rows are used for the solution procedure. A worksheet is created in Microsoft Excel for a small size problem. The Variables as changing cells and constraints are entered in Solver Parameters and a copy of it placed in (Figures 2 & 3). The spreadsheet model yielded an optimal solution for several problems that we tried out.

Parameters are assumed and SOLVER is used that yielded an optimal solution to the problem, i.e. minimized total cost

Conclusion

Now-a-days, world-class ports consider the capacity of Intercontinental distribution as a critical factor for attracting businesses. Successful operation of ports and their capacity impact economic development and growth, industry structure, and employment in the surrounding areas. Port throughput, that is, amount of cargo handled at a port is a function of number of well-equipped berths, cargo loading/unloading equipment, labor organizations condition, and efficiency and effectiveness of various agencies.

This paper describes an intercontinental multi-modal distribution scenario that is formulated as a mixed integer linear mathematical program. A spreadsheet model of the same scenario is also presented and Excel in-build program, SOLVER, is used tom obtain a solution to the problem. Every problem was solved optimally for a feasible set of data. For a balanced problem that has equal number of containers at sources and destinations, the constraints signs should be as used in the example. However, for unbalanced problems, when total number of containers to be shipped from sources is not equal to the total demand at destinations, the sign of some constraints needs to be used according to which of the supply or demand is more. It signs are not correctly used, the problem becomes infeasible.

This model can further be extended to include the unit production costs in addition to shipping costs or be employed as a decision making model for locational analysis when deciding to determine the optimal location of manufacturing facilities. The author acknowledges the assistance provided by his department and his graduate assistant, who helped him in preparing this manuscript.

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