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Mathematical Modeling for Optimization of Time Involved in Container Shipping with Routing

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ABSTRACT: This paper dealing with the idea of optimization of container shipment by using linear programming model, Addressing both the maritime and the inland factors, and taking into consideration of duty check times at ports, customs times check and services frequencies.

KEYWORDS: Load / Origin port, Hub/Gateway port , Discharge/Destination port , routing, customs check, duty check, delay time due to repair/ accidents on way ports, travel time, optimization model by using linear programming and related constrains.

1. INTRODUCTION

From the time of independence, handling of the Indian Sea Ports has recorded a significant growth. The Indian trade fleet strength stood at 1204 vessels with 10.31 million GRT as on end December 2014, representing 54 fold increases in GRT since independence. The outlay and expenditure on the shipping sector have consistently increased over the plan. Also, there had been numerous attempts held by the Indian government along with other private and public sector firms to promote shipping in the country. In the subsequent years, there had been growth in developing countries in a varied level in order to improve their economy. Topping the list are most of the Asian countries.

According to the Ministry of Shipping, around 95% of India's trading by volume and 70% by value is done through maritime transport. In November 2020, the Prime Minister, Mr. Narendra Modi renamed the Ministry of Shipping as the Ministry of Ports, Shipping and Waterways.

India has 12 major and 205 notified minor and intermediate ports. Under the National Perspective Plan for Sagarmala, six new mega ports will be developed in the country. The Indian ports and shipping industry play a vital role in sustaining growth in the country's trade and commerce. India is the sixteenth largest maritime country in the world with a coastline of about 7,517 kms. The Indian Government plays an important role in supporting the ports sector. It has allowed Foreign Direct Investment (FDI) of up to 100% under the automatic route for port and harbour construction and maintenance projects. It has also facilitated a 10-year tax holiday to enterprises that develop, maintain and operate ports, inland waterways and inland ports.

The development in international trade & the removal of trade barriers has made the developing countries to concentrate more on the improvement of their infrastructure, like roads, airports, seaports, which played a vital role in the development of the economy. All these things together with product storage and the capacity to move large shipments have placed the shipping industry in a very advantageous position. Eventually, various other aspects of shipping had been developed over years such as -Containerization, multi-modal transport services, advancement of marine engineering technology, and so on.

Indian Government is working to strengthen its role as gateway for imports and exports. Maritime transport accounts for the largest share of world traffic and, every year, millions of containers are moved. Much of that container traffic is handled by a limited number of gateway ports, whose overloading may result in delays of loading/discharging operations.

This research focus on maritime container transport, with the formulation and test application of a model that benefits from the availability of some real world data and aims to include the inland leg of container transport, albeit in a simplified way, as well as the constraints due to vessel capacity and port processing times. The objective is global travel time minimization. The final goal of this work is to be able to test traffic patterns in terms of their sensitivity to each component of generalized transport costs. Costs associated to ports and inland legs of transport are important since they may make a difference in the choice of ports by the shipping lines and, therefore, on the traffic that roads and

railway in the hinterland of ports have to cope with. The viewpoint of the model may be that of a shipping company that can use it to reduce total shipping times with the resulting increase in service quality.

India exports and imports around 1 million TEU's each, mainly through Bombay, JNPT, and Chennai. USA, Western Europe, and East Asia are the chief destinations through transshipment ports of Dubai, Colombo, and Singapore. Only one Indian player, SCI, has a role in container shipping. However, most of the leading global container lines like NOL-APL, Maersk-Sealand and P&O-Nedlloyd offer services to Indian shippers.

In Section 2, we define the system measured in this work, while the mathematical model is described in Section 3. Finally, Section 4 is dedicated to conclusions and future developments.

II. DESCRIPTION OF SYSTEM

In this paper we consider an intermodal transportation chain composed by three legs. The first one represents maritime transfers from origin ports to doorway/hub ports. Due to the test application we aim for, origin ports are assumed to be located in India while gateway ports are in USA, Europe, Indian subcontinent and Far East.

The second leg of the considered transport chain represents transfers among gateway ports, i.e. in our practical setting transfers between Indian ports due to feeder shipping.

The last leg of the chain represents the inland component of the distribution, in which containers are routed from gateways to final destinations by road, rail or a combined road-rail path.

The system is categorised by three nodes: origin ports, gateway ports and destinations, and two categories of links, maritime and inland. Such elements of the network are described below.

2.1. Handling ports

Assuming without loss of generality, there are three types of handling ports: origin ports, gateway ports (also called transit ports), and destination.

Origin ports do not have any limitation on the capacity and are connected with at least one gateway port (they can even be connected to all gateway ports). No connections among origin ports are considered. For each origin port and each destination, a demand is given, expressed as number of containers travelling from origin port to destination. Containers are supposed to be directly located at the origin port.

Gateway ports/Hub ports, also called transit ports/points, are characterized by a limited capacity of loading/unloading times and duty-check times. Without loss in generality, we are considering only incoming flow, each gateway port is connected with at least one origin port and from origin ports it is possible to reach a gateway port but not vice versa. Gateway ports also may be connected to one another, to represent feeder traffic.

Destinations are located inland and each is connected to the gateway ports with a direct link, representing the shortest path to reach it from that gateway, by road, rail or a combination of the two, and which has been computed in a preliminary phase. Each destination requires a given demand from each origin (which may even be null for some origins).

2.2. Routes

There are two types of routes, maritime and inland, each one with its own characteristics, as described below.

Maritime routes are those between pairs of origin ports and gateway ports as well as those between pairs of gateway ports. International routes may be more than one route connecting an origin port to a gateway port, and each route belongs to a different service with given travel time, limited capacity and frequency. For routes connecting gateways which is computed as the sum of the capacity of all the services operating that route and the travel times are expressed in days.

Considering the inland routes are to be direct routes, the shortest path between a gateway port and a destination is given as input and calculated in advance by a separate model working on an inland system, and able to account for different modes (rail, road and combined paths). Travel times on inland links are expressed in hours. Inland services are assumed to be immediately available with no limit & congestion when requested. This may be assumed to hold true for road transportation since it is carried out by dedicated trucks, but it is generally not true for rail services.

III. MODEL FORMULATION

Container shipment is a cost focused problem, it is very difficult to identify actual routing costs and generalised routing costs. Travel times and service frequencies are available on the web, whereas the actual costs are very difficult to be determined before the shipment. However we can calculate approximate total cost based on the shipment routing and



can vary considerably during the year. Our aim is to construct a real time linear programming model for this problem which may be solved to optimality by using travel time costs to be minimized.

3.1. Notations and Objective function

Let us take the following ideas and factors to be used as input data for this model:

- O set of origin ports
- D set of destinations
- H set of hub / gateway ports
- S set of services
- R_1 set of routes connecting an origin to a Hub (first-leg arcs)
- R_2 set of routes connecting two Hub (second-leg arcs)
- T_{1a} travel time on route a (expressed in days)
- D_{1a} Delay time due to repair/ accidents on route
- T_{2b} travel time on route b (expressed in days)
- D_{2b} Delay time due to repair/ accidents on route
- T_{3hd} inland travel time from port h to destination d (expressed in hours)
- D_{3hd} Delay time due to repair/ accidents from port h to d
- E_h duty-check times at port h (expressed in days)
- C_o Customs Check at Origin port (expressed in days)
- Q_{od} demand of containers from origin o to destination d
- L_s capacity of service s (expressed in number of containers)
- M_b capacity of link b (expressed in number of containers)
- F_{1a} frequency with which route a is operated
- F_{2b} frequency with which route b is operated
- o_a origin from which route a starts
- d_a gateway where route a arrives
- σ_a service to which route a belong
- i_b gateway from which route b starts
- j_b gateway where route b arrives
- γ scaling factor

And the following variables:

- X_{ad} integer variable representing number of containers traveling on route a directed to destination d
- Y_{bod} integer variable representing number of containers traveling on route b arriving from origin o and directed to destination d
- Z_{ohd} integer variable representing number of containers coming from origin o and traveling on the inland network from gateway port h to final destination d
- Z_o integer variable representing number of containers loading from origin o and traveling on the inland network from gateway port h to final destination d
- W_{1ad} continuous variable representing waiting time on route a for containers directed to destination d
- W_{2bod} continuous variable representing waiting time on route b for containers arriving from origin o and directed to destination d

The mathematical model can be formulated as follows

Objective function is

$$\text{Min } \sum_{a \in R_1} \sum_{d \in D} T_{1a} X_{ad} + \sum_{a \in R_1} \sum_{d \in D} D_{1a} X_{ad} + \sum_{b \in R_2} \sum_{o \in O} \sum_{d \in D} T_{2b} Y_{bod} + \sum_{b \in R_2} \sum_{o \in O} \sum_{d \in D} D_{2b} Y_{bod} + \gamma \sum_{o \in O} \sum_{h \in H} \sum_{d \in D} T_{3hd} Z_{ohd} + \gamma \sum_{o \in O} \sum_{h \in H} \sum_{d \in D} D_{3hd} Z_{ohd} + \sum_{a \in R_1} \sum_{d \in D} W_{1ad} + \sum_{b \in R_2} \sum_{o \in O} \sum_{d \in D} W_{2bod} + \sum_{o \in O} \sum_{h \in H} \sum_{d \in D} E_h Z_{ohd} + \sum_{o \in O} C_o Z_o \text{ ----- (1)}$$

$$\sum_{a \in R_1 / \sigma_a = o} X_{ad} = Q_{od} \quad \forall o \in O, \forall d \in D \text{ ----- (2)}$$

$$\sum_h Z_{ohd} = Q_{od} \quad \forall o \in O, \forall d \in D \text{ ----- (3)}$$

$$\sum_{a \in R_1 / \sigma_a = o \wedge d_a = h} X_{ad} + \sum_{b \in R_2 / j_b = h} Y_{bod} = Z_{ohd} + \sum_{b \in R_2 / i_b = h} Y_{bod} \quad \forall o \in O, \forall d \in D \forall h \in H \text{ ----- (4)}$$

$$\sum_{a \in R_1 / \sigma_a = s} \sum_{d \in D} X_{ad} \leq L_s \quad \forall s \in S \text{ ----- (5)}$$

$$\sum_{o \in O} \sum_{d \in D} X_{bd} \leq M_b \quad \forall b \in R_2 \text{ ----- (6)}$$

$$X_{ad} \leq F_{1a} W_{1ad} \quad \forall a \in R_1 \quad \forall d \in D \quad \text{----- (7)}$$

$$Y_{bod} \leq F_{2b} W_{2bod} \quad \forall b \in R_2 \quad \forall o \in O \quad \forall d \in D \quad \text{----- (8)}$$

$$X_{ad}, Y_{bod}, Z_{odh} \in Z^+ \quad \forall o \in O, \forall d \in D, \forall h \in H \quad \text{----- (9)}$$

The objective function (1) is compiled by ten terms. The first six terms are related to time spent: sailing from origin to doorway ports; delay time due to repair/accidents; between doorway ports; and with the inland element of the system. Waiting times are expressed by the seventh and eighth terms, for first-leg and second-leg routes, respectively. Duty check times & customs check times are taken into account by the ninth term and tenth terms respectively. Constraints (2) and (3) ensure demand satisfaction, while flow balance at transit nodes (doorway ports) is assured by constraint (4). Constraints (5) and (6) ensure that services capability along the first-leg fulfil with the link capacity along the second-leg. Constraint (7) and (8) fix stay times at ports with incoming flows and service frequencies. As stated in Bell et al. (2011), this constraints allow the identification of more attractive paths, instead of only the shortest one, and split the container assignment among them, limiting delays in the transportation process given by ports congestion and overcrowding. Finally, constraints (9) define the domains of variables.

IV. CONCLUSION

In this study we dealt with container shipment optimization on an intermodal system. We recommend a linear programming model, following a frequency based method, addressing both the maritime and the inland factors, and taking into consideration of duty check times at ports, customs times check and services frequencies. Computational results show the efficiency and the effectiveness of the approach proposed, even on large size instances. Future developments would involve calibrating the model parameters including actual shipping costs, travel times and externalities. A further experiment could be the development of heuristic algorithms able to address all worldwide shipping operations.

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