Indian Journal of Geo Marine Sciences
Vol. 48 (03), March 2019, pp. 397-402

Supply chain integration through ship routing optimization among BRICS by using meta-heuristic technique

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Received 04 August 2017; revised 08 January 2018

Acquiring and distribution of goods among BRICS countries by way of supply chain integration through route optimization of a fleet of vessels to serve customers of coined members with minimum total cost and sum of demurrage cost (charged by port) and detention cost (charged by ocean carriers), arising from earliness and tardiness in ship's arrival at ports with respect to the delivery deadlines of customers, is a homogeneous heterogeneous ship routing problem with time window (HHSRPTW), which involves the routing of a set of ships with known demands and predefined time windows as well as delivery time. To solve the problem, this study proposes a genetic algorithm as an optimization technique and MATLAB as a software tool.

[**Keywords**: Maritime transportation, Freight forwarder, Hinterland, Detention, Demurrage, Ocean carrier]

Introduction

BRICS is a notation of an organized association of emerging market economies of South Africa, Brazil, Russia, India, and China. All BRICS countries are distinguished by their drastic enhancement in their economies that has considerable influence on regional and international affairs. These countries represent population strength of 3 billion people with combined GDP[1-3] $ 14.9 trillion.

This study is an attempt to facilitate trading enhancement among BRICS countries by optimizing sea routing to maintain the inventory in the prescribed lead time, by connecting ports of BRICS with the shortest distance of sea route to attain the customer commitment taking into consideration all input variables, output variables, decision variables and constraints. It is impractical for any country to have proficiency to produce all types of required inventory because of non-availability of high technology, skilled labor, and appropriate machines. So it is important to connect five countries for inventory maneuver through optimized route with minimum total cost and sum of demurrage cost (charged by port) and detention cost (charged by ocean carriers), arising from earliness and tardiness in ship's arrival at ports with respect to the delivery deadlines of customers[4].

BRICS plays an important role in technological, economic, commercial and social network activities expansion among the member countries and integration of their international trade. The availability of products and services in one country/other parts of the world becomes promptly accessible or procurable by using advance communication tools and techniques. Coined countries, realizing the positive outcome of international economic integration, have attempted fostering this strategy for implementation. One of the most impacting force behind international integration of BRICS countries in efficient implication of logistics and distribution[5] system is facilitating the movement of cargo or shipment from supply end to delivery end or point of origin to the point of distribution, economically in terms of cost, speed and reliability.

BRICS trading integration also can be made possible through land, air and sea. The most popular land-based logistics are buses, trains, and trucks that are not flexible and efficient with respect to distance and amount of cargo they can cover and carry per round. Long distance transition of the shipment requires remaining modes of transportation, either by air or sea. Air-based logistics are fast, secure with strictly maintained safety standard, making them ideal for the transportation of perishable products; but they have limitations on size, weight, and high costs[6]. The third mode of logistics is maritime transportation. Nearly 65% to 85% international trade by weight is done by shipping fleet, and 90% of the global cargo is moved by shipping using different types of vessels[7-10] (different speed and capacity) as per demand needed among BRICS countries.

Mathematical Model Formulation

Objectives

The first goal of the model formulation is to minimize the total cost of transportation among BRICS countries by designing the optimal routes and considering three types of costs based on impact and their magnitude:

Acquiring cost (from origin city to origin port)

Routing cost (sailing cost/bunker cost, from port to port, which is 60% of the total ship operating costs[11]

Trans-shipment costs (internal and external)

Distributing cost (from destination port to destination city)

Table 1A ─ Notations in the mathematical model Parameter & definition

$p \in P$	Set of ports of BRICS countries
$c \in C$	Set of cities of BRICS countries
$t \in T$	Set of train operator of BRICS countries
$r \in R$	Set of road operator of BRICS countries
$f \in F$	Set of road-train (combined) operator of BRICS countries
$s \in S$	Set of ships
$k \in K$	Set of shipment between origin and destination city
$o \in O$	Set of origin point
$d \in D$	Set of destination point
Q_{p_o}	Capacity of origin ports
Q_{p_d}	Capacity of destination ports
Q_t	Capacity of train operator (train)
Q_r	Capacity of road operator (truck)
Q_f	Capacity of road-train (combined) operator
Q_s	Capacity of ships between port to port
$X_{1c_op_otk}$	Number of transported TEU between origin city and origin port by train
$X_{2c_op_ork}$	Number of transported TEU between origin city and origin port by road
$X_{3c_op_ofk}$	Number of transported TEU between origin city and origin port by road-train (combined)
$\alpha_{1c_op_ot}$	Transportation cost of 1 TEU between city and port via train operator
$\alpha_{2c_op_or}$	Transportation cost of 1 TEU between city and port via road operator
$\alpha_{3c_op_of}$	Transportation cost of 1 TEU between city and port via road-train (combined) operator
Y_{ppsk}	No of transported TEU between origin port and destination port by shipping line
β_{pps}	Transportation cost of 1 TEU between origin port to destination port by shipping line
$Z_{1p_dc_dtk}$	Number of transported TEU between destination port and destination city by train
$Z_{2p_dc_drk}$	Number of transported TEU between destination port and destination city by road (truck)
$Z_{3p_dc_dfk}$	Number of transported TEU between destination port and destination city by road-train (combined)
$\gamma_{1p_dc_dt}$	Transportation cost between destination port and destination city by train operator
$\gamma_{2p_dc_dr}$	Transportation cost between destination port and destination city by road operator
$\gamma_{3p_dc_df}$	Transportation cost between destination port and destination city by road-train (combined) operator
W_{dp_ok}	Total demand at origin port
W_{dp_dk}	Total demand at destination port
W_{dc_dk}	Total demand at destination city
$U_{p_op_dsk}$	Total number of transported TEU between port and port by shipping line
μ_o	Detention Charges of 1 TEU
N	Number of days after expiry of free days for Detention Charge
μ_d	Demurrage Charges of 1 TEU
M	Number of days after expiry of free days for Demurrage Charge

Table 1B ─ Notations in the mathematical model: Objective function

$$Min \sum_{c\in C}\sum_{p\in P}\sum_{t\in T}\sum_{k\in K} \alpha_{1c_o p_o t} * X_{1c_o p_o tk} + \sum_{c\in C}\sum_{p\in P}\sum_{f\in F}\sum_{k\in K} \alpha_{3c_o p_o f} * X_{3c_o p_o fk} + \sum_{p\in P}\sum_{s\in S}\sum_{k\in K} \beta_{pps} * Y_{ppsk}$$

$$+ \sum_{p\in P}\sum_{c\in C}\sum_{t\in T}\sum_{k\in K} \gamma_{1p_d c_d t} * Z_{1p_d c_d tk} + \sum_{p\in P}\sum_{c\in C}\sum_{r\in R}\sum_{k\in K} \gamma_{2p_d c_d r} * Z_{2p_d c_d rk} + \sum_{p\in P}\sum_{c\in C}\sum_{f\in F}\sum_{k\in K} \gamma_{3p_d c_d f} * Z_{3p_d c_d fk}$$

$$+ \sum_{p\in P}\sum_{c\in C}\sum_{f\in F}\sum_{k\in K} N * \mu_o + \sum_{p\in P}\sum_{c\in C}\sum_{f\in F}\sum_{k\in K} M * \mu_d$$

Constraints

1. Demands

$$\sum_{p\in P}\sum_{t\in T} X_{1c_o p_o tk} + \sum_{p\in P}\sum_{t\in T} X_{2c_o p_o rk} + \sum_{p\in P}\sum_{t\in T} X_{3c_o p_o fk} = W_{dp_o k} \ \forall k \in K$$

$$\sum_{p\in P}\sum_{s\in S} Y_{ppsk} = W_{dp_d k} \ \forall k \in K$$

$$\sum_{p\in P}\sum_{t\in T} Z_{1p_d c_d tk} + \sum_{p\in P}\sum_{t\in T} Z_{2p_d c_d rk} + \sum_{p\in P}\sum_{t\in T} Z_{3p_d c_d fk} = W_{dc_d k} \ \forall k \in K$$

2. Total no. of transported TEU

$$\sum_{t\in T} X_{1c_o p_o tk} + \sum_{r\in R} X_{2c_o p_o rk} + \sum_{f\in F} X_{3c_o p_o fk} = U_{p_o p_d sk} \ \forall o \in O, \forall k \in K$$

$$\sum_{t\in T} Z_{1p_d c_d tk} + \sum_{r\in R} Z_{2p_d c_d rk} + \sum_{f\in F} Z_{3p_d c_d fk} = U_{p_d p_o sk} \ \forall d \in D, \forall k \in K$$

3. Capacity

$$\sum_{d\in D}\sum_{s\in S}\sum_{k\in K} U_{p_o p_d sk} \le Q_{p_o} \ \forall o \in O$$

$$\sum_{o\in O}\sum_{s\in S}\sum_{k\in K} U_{p_o p_d sk} \le Q_{p_d} \ \forall d \in D$$

$$\sum_{k\in K} X_{1c_o p_o tk} \le Q_t \ \forall o \in O, \forall t \in T$$

$$\sum_{k\in K} X_{2c_o p_o rk} \le Q_r \ \forall o \in O, \forall r \in R$$

$$\sum_{k\in K} X_{3c_o p_o fk} \le Q_f \ \forall o \in O, \forall f \in F$$

$$\sum_{k\in K} Y_{ppsk} \le Q_s \ \forall s \in S$$

$$\sum_{k\in K} Z_{1p_d c_d tk} \le Q_t \ \forall d \in D, \forall t \in T$$

$$\sum_{k\in K} Z_{2p_d c_d rk} \le Q_r \ \forall d \in D, \forall r \in R$$

$$\sum_{k\in K} Z_{3p_d c_d fk} \le Q_f \ \forall d \in D, \forall f \in F$$

The second goal is to minimize the sum of demurrage cost (charged by port) and detention cost (charged by ocean carriers), arising from earliness and tardiness in ship's arrival at ports with respect to the delivery deadlines of customers[12].

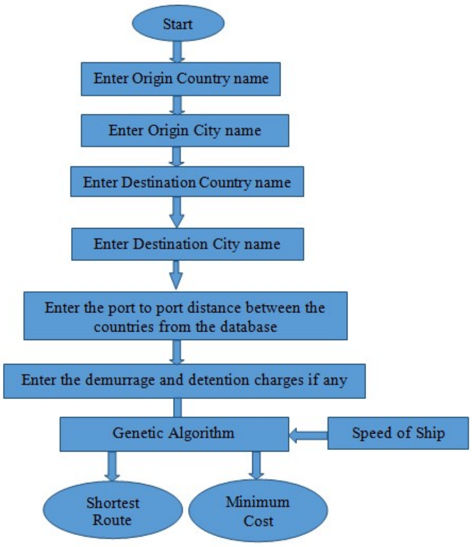


Fig. 1 — Flow chart for Algorithm

Modeling Assumptions

There is only containers trading with heterogeneous and homogeneous ships Origin to destination demand can be divided into number of shipments followed by different paths and/or modes, There is time constraint Origin to destination demand is known and therefore the problem results in deterministic mode.

Solution Approach

For solving heterogeneous homogeneous ship routing problem with time window (HHSRPTW), genetic algorithms are proposed inspired by Darwin's theory about evolution. The algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope that the new population will be better than the old one. Solutions which are selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are the more chances they have to reproduce. This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.

Illustration of Shipment between Brazil to China with Brasilia and Shanghai as the origin and destination city, respectively

Let B be the distance in kms between major cities and major ports of brazil, then B=

From /To	Belem B1	Fortaleza B2	Paranagua B3	Recife B4
Brasília	1939	2106	1426	2133
São Paulo	2648	2969	447	2,648
Rio de Janeiro	2299	2620	890	2,299
Belo Horizonte	2028	2349	1,034	2,028
Salvador	805	1227	2,420	805

As we considered earlier that Brasilia be the origin City, as seen that Paranagua is near to Brasilia. Now, destination city be C, and Bahezhen is nearer to Shanghai. C=

From /To	Zhanjiang C1	Bahezhen C2	Port of Xiamen C3	Port of Tianjin C4
Shanghai	1898	844	1035	1109
Beijing	2568	1147	2113	140
Shenzhen	506	1027	609	2164
Suzhou	1865	744	1021	1016
Guangzhou	420	1018	706	2155

Let BC be the port-to-port distances between two countries, when BC=

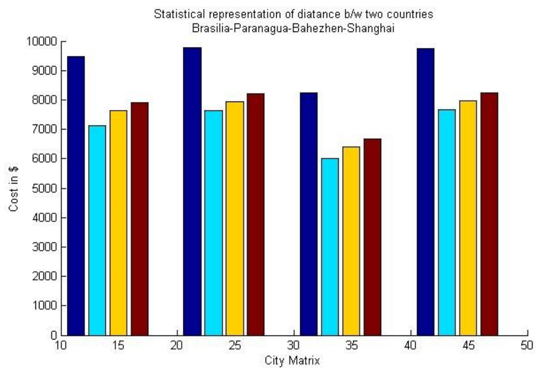
From /To	Zhanjiang C1	Bahezhen C2	Port of Xiamen C3	Port of Tianjin C4
Belem B1	13674	12792	14226	15509
Fortaleza B2	12934	14559	13497	14780
Paranagua B3	12169	13059	12702	13985
Recife B4	11979	14181	13119	14401

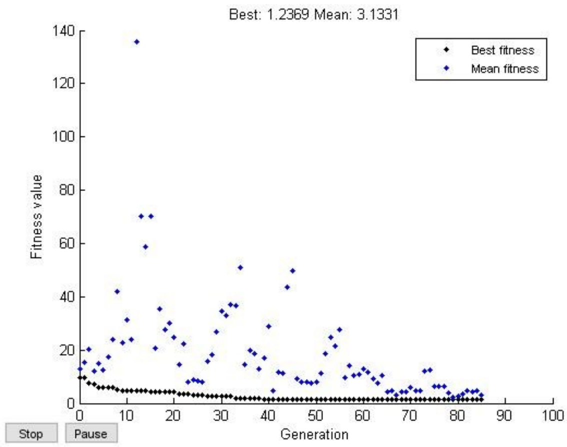
Results

From the matrices, B and C are clearly the shortest route seen, but if we consider all the shortest paths specially routes from matrix BC, the genetic algorithm is applied to find the shortest path from all the possible paths. In matrix BC, although the highlighted number is not the shortest route, but this result comes after optimizing all possible routes.

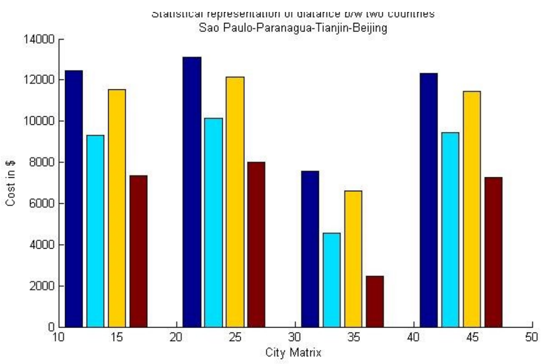
1. Brazil-China

a. Brasilia-Shanghai



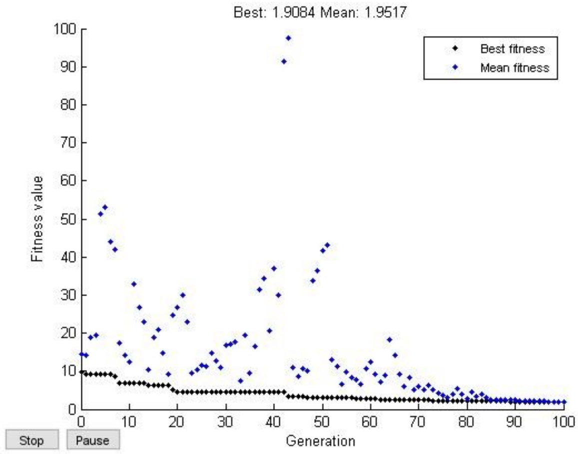


b. Sao Paulo-Beijing

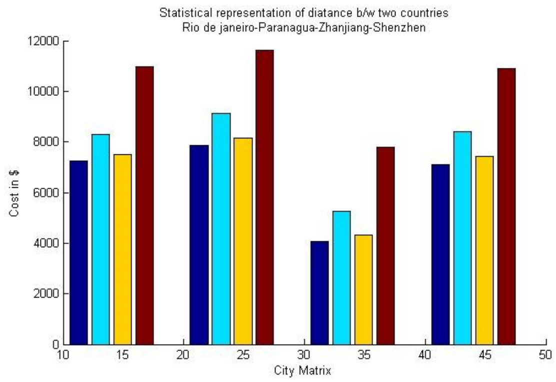


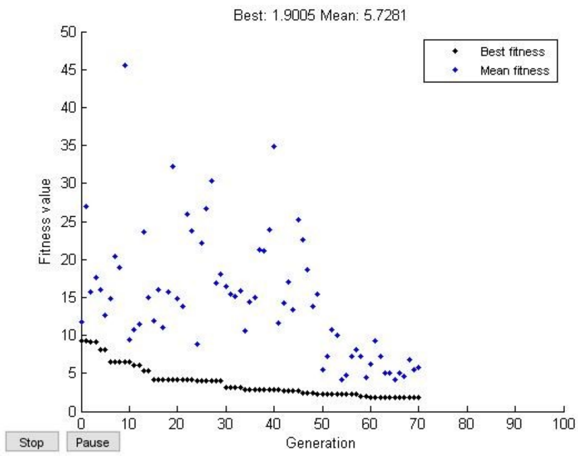
The results below show the optimized cost to ship 1 TEU.

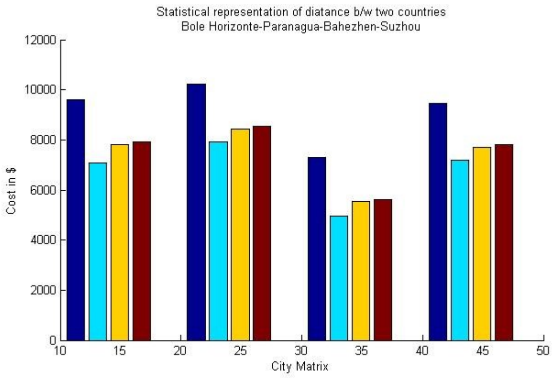
The statistics shown below consists of four groups, all four groups represent the rows of matrix BC and sub-elements of each group represent a column.

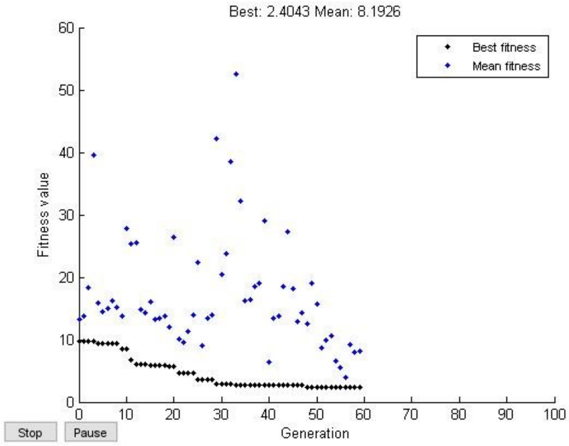


c. Rio de Janeiro-Shenzhen









Conclusion

This study has considered a new extension of ship routing problem with time windows, namely the Homogeneous Heterogeneous Ship Routing Problem with Time Windows (HHSRPTW), which can be applied to the BRICS countries distribution problems to achieve agenda of summit of coined term, which is economic trading enhancement. The proposed mathematical formulation of HHSRPTW is followed by implementation of genetic algorithm as meta-heuristics technique to optimize the costs of transportation done by ocean (ship) and road transport (trucks, trains) in form of acquiring, shipping and distribution cost and minimizing the sum of demurrage cost (charged by port) and detention cost (charged by ocean carriers), arising from earliness and tardiness in ship's arrival at ports with respect to the delivery deadlines of customers. If delivery time is more than the normal time to reach the destination, then slow speed is recommended to avoid the above mentioned charges, as ship arrives too early or too late. In both cases, cost is charged by port and carrier, which is minimized by selecting suitable speed of ship, according to the required delivery time.

Acknowledgement

The authors would like to thank the departmental research evolution committee members for their valuable suggestions, thereby improving the quality of this research work.

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