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Optimization of Energy Consumption in a Maritime Transit Network

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Abstract

Seaports are a major influencer on a country overall economy. Saudi Arabia is located at the pass ways between the East and the West. More than 90% of shipments are transported by ships. Many manufacturers assemble their products in locations that are connecting shipping routes. This study aims to replace Jebel Ali port by Saudi Arabian ports while trying to minimize the total fuel consumption for a set of container vessels routes. The Transshipment problem was solved through Tora Optimization Software. The solution showed the importance of routing the container vessels through Jeddah Islamic Port, being located to open routes (on the way between the Red sea and the Mediterranean Sea) not like ports located in the Arab sea (dead end) and the need for double turns. The results where simulated and animated via Arena Rockwell Software. The results shows the need to re-innovate and expand Jeddah Islamic Port. Jeddah Islamic Port has to be marketed through the available crude oil Refinery to motivate the routing of ships through it by lowering the HFO Prices.

Keywords
HFO; Terminal; Seaport; Container Vessel; Schedule

1. Introduction
The maritime sector is a key asset for the world economy, but the sector is primarily supplied with Heavy Fuel Oil (Prussi 2021). The main mode of transport for global trade is sea shipping: around 90% of traded goods are carried over the waves. In a study that have compared four types of maritime vessels based on their Total Operational Cost. The results showed that a Feeder vessel with Fast Speed and a Large Capacity Fuel Costs equals 43% of the total operational cost (Colling 2020) (Figure 1).

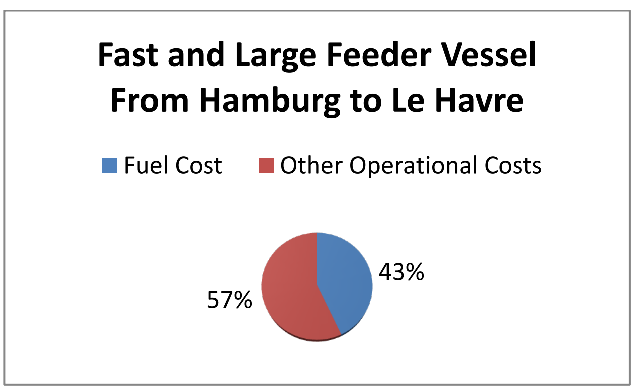

Figure 1. Distribution of Vessels Operational cost via Pie chart for Fast and Large Feeder Vessel from Hamburg to Le Havre

The purpose of the hub-and-spoke system is to save shipping companies money and provide shippers with better routes to their destinations. Vessels are shipping company's most valuable asset. This paper attempts to identify a generic transportation matrix model for reducing the Energy consumption (Measured in Tera Joule) for routing container vessels through Saudi Arabia Sea ports, using the hub-and-spoke model. The model is subjected to the supply and demand constraints at seaports levels. This paper hub-and-spoke shipping network, is shown in Figure 2, will be analyzed in this paper. The network has (*j*) hubs, and each hub has (*i,k*) spoke seaports connecting it to other parts of the network. This paper will investigate covering a group of seaports. The next step is to locate a route matrix that, when applied and simulated to the overall network, ships capable of meeting the transportation requirements of Transit Goods while simultaneously reducing their overall Energy consumption.

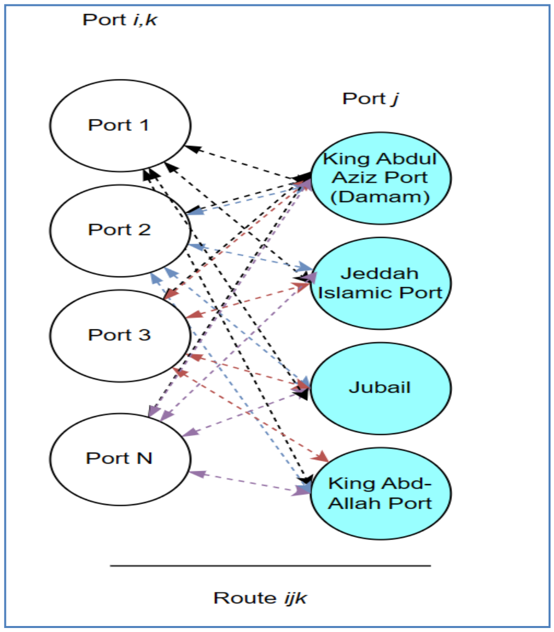

Figure 2. Saudi Seaport Hubs Network

2. Theoretical Background

At the design level, Maersk's new 18,000 TEU 'Triple-E'1 containerships have a design speed of 17.8 knots, down from the 22–25 knots range that has been the industry's norm, and will emit 20% less CO2 per container moved as compared to the Emma Maersk, previously the world's largest container vessel, and 50% less than the industry average on the Asia–Europe trade lane (Maersk, 2013). See Figure 3 for the plotted Load, Speed and fuel consumption for a specific vessel.

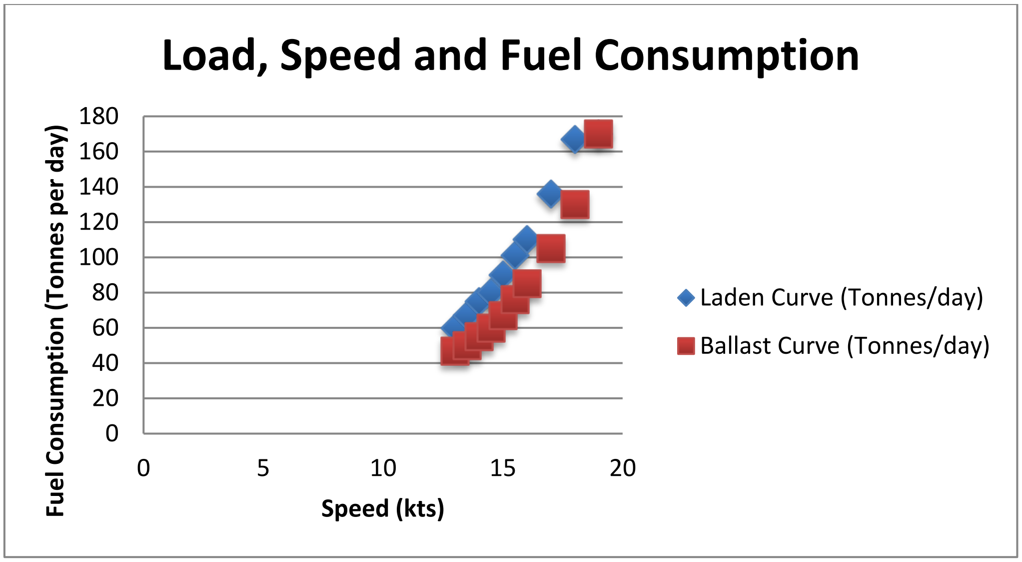

Figure 3. Load, Speed and Fuel Consumption.

A study for the estimation of fuel consumption in a hub and spoke airliner network, have break-down the airliner travelling costs between a hub and spoke network to connect between high demanded routes (AL-Tahat et al. 2019). Thus, by replacing a major near-by hub Sea port such as Jebel Ali Port by a major Saudi Sea ports the network shall look like Figure 4 below.

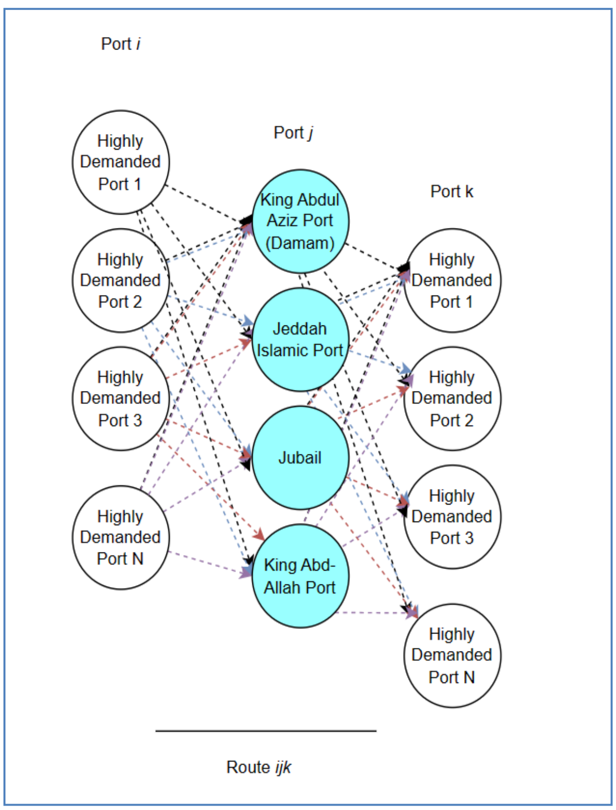

Figure 4. Containerized Vessel Suggested Transit Network

A study has scheduled the flow of highly demanded airlines transit routes in an effort to replace Dubai international airport (considered as a pure transit airport) by King Abdul Aziz international airport in Jeddah and King Khaled international airport in Riyadh (AlSahli et al. 2024).

In a study that proposes a hub-and-spoke network design for container shipping in inland waterways based on the tree-like structure river. Firstly, the characteristics of the hub-and-spoke network in the inland waterways were presented. Then, an integer linear programming model is proposed to simultaneously determine the optimal hub location, feeder port allocation, and fleet deployment to minimize the total cost of ships, transportation, and transshipment. A decomposition-based math-heuristic method that is developed upon the researcher's logic and an enhanced genetic algorithm are then proposed to solve the network design. A case study based on the traffic on the Yangtze River and extensive computational experiments are conducted to verify the effectiveness of the proposed models and methods (Hu et al. 2021, Zhou et al. 2023).

A research conducted on the relationship of route design, fleet planning and container freight to build the objective function in view of the minimization of time and cost. This study proposes the mixed integer linear programming model of hub-and-spoke network and liner ship fleet planning to choose the appropriate ship location (assigned routes) and distribution, and applies Lagrange Heuristic Algorithm to solve the model. The verified the results via simulating the results. Lagrange Heuristic Algorithm can get high quality solutions in a relatively short time, it provides reference significance for solving related problems in the future, however the solution is the beast among alternatives but it is not considered optimal (Bai and Fan 2023).

In a research effort on a study problem containing elements of the Hub-and-Spoke and Travelling Salesman, with different levels of passenger flows among islands (Figure 5),

The hub selection within nodes and the shortest routes among islands are internal optimization goals. This work introduces a multi-objective tri-level optimization algorithm for the General Network of Short Sea Shipping (GNSSS) problem to reduce travel distances and transportation costs while improving travel quality and user satisfaction, mainly by minimizing passenger hours spent on board (Farmakis et al. 2023).

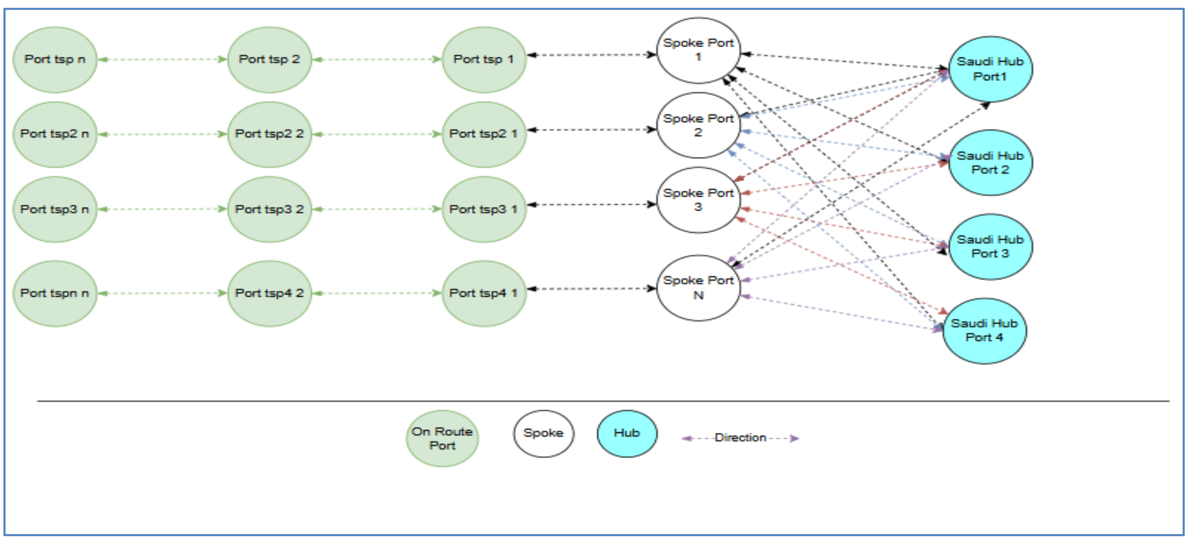

Figure 5. Ships Routed through a Set of Sea ports

Saudi Arabia occupies the majority of the Arabian Peninsula. Located in Western Asia, the country borders the United Arab Emirates, Oman, Qatar, Bahrain, Kuwait, Jordan, Iraq and the Red Sea. Saudi Arabia is a major trading partner with countries in the region as well as internationally which is why its ports are crucial to the country's economy.

- Jeddah Islamic Port
  According to the Saudi port authority website (2024), Jeddah Islamic Port is the primary gateway to the Holy Mosque in Mecca for Muslim pilgrims from around the world. Having enjoyed historical significance since it

was established in 646 AD during the reign of the Caliph Uthman ibn Affan, the port today is the biggest gateway for Saudi Arabia's imports and exports and the Red Sea's top re-export point, with 75 percent of the country's exports and inbound transshipment going through it.
According to the Saudi port authority website (2024), hub container terminal at Jeddah were prepared considering yard operations for rubber tyred gantry crane (RTG's), straddle carrier and forklift operations were developed. The port consists of two container terminals with a combined capacity of 7.5 million TEUs

- Dammam Port
  According to the Saudi Port Authority website (2024), King Abdul-Aziz Port is the main port of the country in the Arabian Gulf and it handles a large share of the export services for the oil industry. The port features a refrigerated cargo terminal, two general cargo terminals, shared container and bulk grain terminals as well as 1st and 2nd container terminals.
- Jubail Port
  According to the Saudi Port Authority website (2024), This port handles the commercial cargo in Jubail including general, container and bulk cargo. With a capacity of 1 million TEUs annually this port provides an alternate gateway to Saudi Arabia's regional and international markets. The container terminal of Jubail Commercial Port is also very well equipped with the berth capacity at the port reaching 36 million tones.
- Jebel Ali Port
  According to DP world website (2024), Jebel Ali Port have 4 terminals with the Following Specs:

- Terminal 1
  Container Terminal 1 (T1) has a capacity of 9 million TEU and is one of the busiest terminals.
- Terminal 2
  Container Terminal 2 (T2) with 32 quay cranes and 8 berths has a capacity of 6.5 million TEU.
- Terminal 3
  Container Terminal 3 (T3) is known for its remarkable technological achievements. It has 5 berths and a capacity of 3.8 million TEU.
- Terminal 4
  Container Terminal 4 (T4) will be the next benchmark for the world of trade with capabilities designed to serve the current and future market requirements. On its completion, it will take the port capacity to 22.4 Million TEU.

A research studied the development and simulation analysis of real-time, dual-load yard truck control systems for seaport container transshipment terminals. The model is designed to reproduce the microscopic, stochastic, real-time environment at a multiple-berth facility. In 2007, the proportion of transshipment cargo at the world's busiest container port, Singapore, was about 80%. Transshipment cargo also had a 50% share at two other ports in Dubai (Jebel Ali) and Kaohsiung.

3. Model formulation and real-life case

The following notations and annotations are used to formulate the optimal solution:
N: Total number of origin ports
M: Total number of destination ports
i: origin port, i=1,2,3…..N
j: destination port, j=1,2,3,…..M

c_{ij} : Total Heavy Fuel Oil Consumption in Tons to Transport a container vessel from port *i* to port *j*. where $c_{ij} = d_{ij}.f.$(Tons.)

d_{ij} : Travel duration between origin *i* and destination port *j*. (hr.).

f: Rate of Fuel Consumption for a specific vessel speed (Fuel Efficiency). ($\frac{Tons}{hr.}$)

x: $Average\ Speed\ of\ a\ Vessel.$ ($\frac{Knots}{hr}$.).
a_i: $Departures\ from\ port\ i$
b_j: $Arrivals\ to\ port\ j$

S_{ij} : Allocated number of container vessels between origin *i* and destination *j.*

The objective is to minimize the total Energy consumption as follow:

$$\text{Min } Z = \sum_{i=1}^{N}\sum_{j=1}^{M} c_{ij}s_{ij} \ldots..(1)$$

Subject to:

$$a_i = \sum_{j=1}^{N} s_{ij} \ldots\ldots(2)$$
$$b_j = \sum_{i=1}^{M} s_{ij} \ldots\ldots.(3)$$
$$\sum_{i=1}^{N} a_i = \sum_{j=1}^{M} b_j \ldots..(4)$$

Where;
$s_{ij} \geq 0, c_{ij}=\infty$ when i=j, j= {1,2,….M}, i= {1,2,….N}

In order to minimize the total fuel and energy consumption to connect container vessels shipping networks, this paper has the following steps:

a) Setting the hub and spoke seaports for a specific type of container vessels: Through a paid subscription in a well-known website for tracking sea vessels, data has been collected from vesselfinder.com for Jebel Ali Seaport Arrivals and Departures for the duration between 12th May 2024 until 11th June 2024. The data has been filtered for container vessels of a volume of around 20,000 TEU. The study has sorted the spoke seaports to be having more than 2 Arrivals/Departures. Table 1 below shows that Jebel Ali port have 13 container vessels arriving from Khalifa port, 9 container vessels arriving from Singapore port, 4 container vessels arriving from Valencia, 5 container vessels from Algeciras port, 6 container vessels from Salalah port and 2 container vessels from Dammam port. Jebel Ali port also for the same duration and for the similar type of vessels have 4 departures to Singapore port, 2 departures to Valencia, 14 departures to Tanger, 3 departures to Dammam, 4 departures to Klang port, and 2 departures to Qasim Port. the data collected from vesselfinder.com (2024). Jebel Ali port has been chosen to be replaced by Saudi seaports. Thus, according to marineinsight.com (2024), Jebel Ali port has been ranked as the 8th busiest seaport in the world and acting as a transit port, which gather different containers from different sources to be shipped to specific destinations (Table 1).

Table 1. Case Hub and Spoke Seaports

ID	Port	Country	Supply/Arrivals at Jebel Ali	Demand/Departures at Jebel Ali
1	**Khalifa Port**	UAE	13	
2	**Singapore Port**	Singapore	9	4
3	**Valencia Port**	Spain	4	2
4	**Tanger Port**	Morocco	5	14
5	**Algecrias Port**	Spain	4	
6	**Salalah Port**	Oman	6	
7	**Dammam Port**	KSA	2	3
8	**Klang Port**	Malaysia		4
9	**Port Qasim**	Pakistan		2
10	**Jebel Ali**	UAE		
11	**Jubail**	KSA		
12	**Jeddah Islamic Port**	KSA		

b) Calculating the total fuel consumption in tons for the connections between the preset spoke seaports and the hub seaports: the modeling of a fuel consumption prediction model for ocean-going container ships and based on sensor data was built [8], the study gives the following equation for the estimation of a 20,000 TEU HFO container ship fuel consumption :

Fuel consumption per hour in tons= $f = 0.015\, x^3 - 0.39x^2 + 13.19x - 92.43 \ldots \ldots . . equation\ (5)$
Where at an average speed of 14 Knots, the hourly fuel consumption equals: $f = 0.015\, x^3 - 0.39x^2 + 13.19x - 92.43 = 184.66$

The durations between two ports at a speed of 14 Knots was gathered from ports.com (2024) website.

The Total fuel consumption in tons= $24 \times f . d_{ij} \ldots . equation\ (6)$

Table 2 below shows the total fuel consumption in (HFO.Tons) = 959,601.6 Tons to connect the spoke seaports via Jebel Ali Port. Figure 6 shows the connections of spoke seaports via Jebel Ali port, where 43 container vessels arrived to Jebel Ali port and 29 container vessels have departed from Jebel Ali port (Table 2).

Table 2. Total Fuel Cost For Transit Vessels through Jebel Ali Port

Origin	Destination 10	Duration	Consumption per day in Tons	Total Fuel Consumption in Ton	Supply	Demand
1	302	0.9	1,374	1,236.6	13	
2	397	11.8	1,374	16,213.2	9	4
3	5,071	15.1	1,374	20,747.4	4	2
4	5,406	16.1	1,374	22,121.4	5	14
5	5,377	16	1,374	21,984	4	
6	999	3	1,374	4,122	6	
7	389	1.2	1,374	1,648.8	2	3
8	3,741	11.1	1,374	1,5251.4		4
9	746	2.2	1,374	3,022.8		2
Supply Total Fuel Consumption (HFO.Tons)						471,556.8
Demand Total Fuel Consumption (HFO.Tons)						488,044.8
Total Fuel Consumption (HFO.Tons)						959,601.6

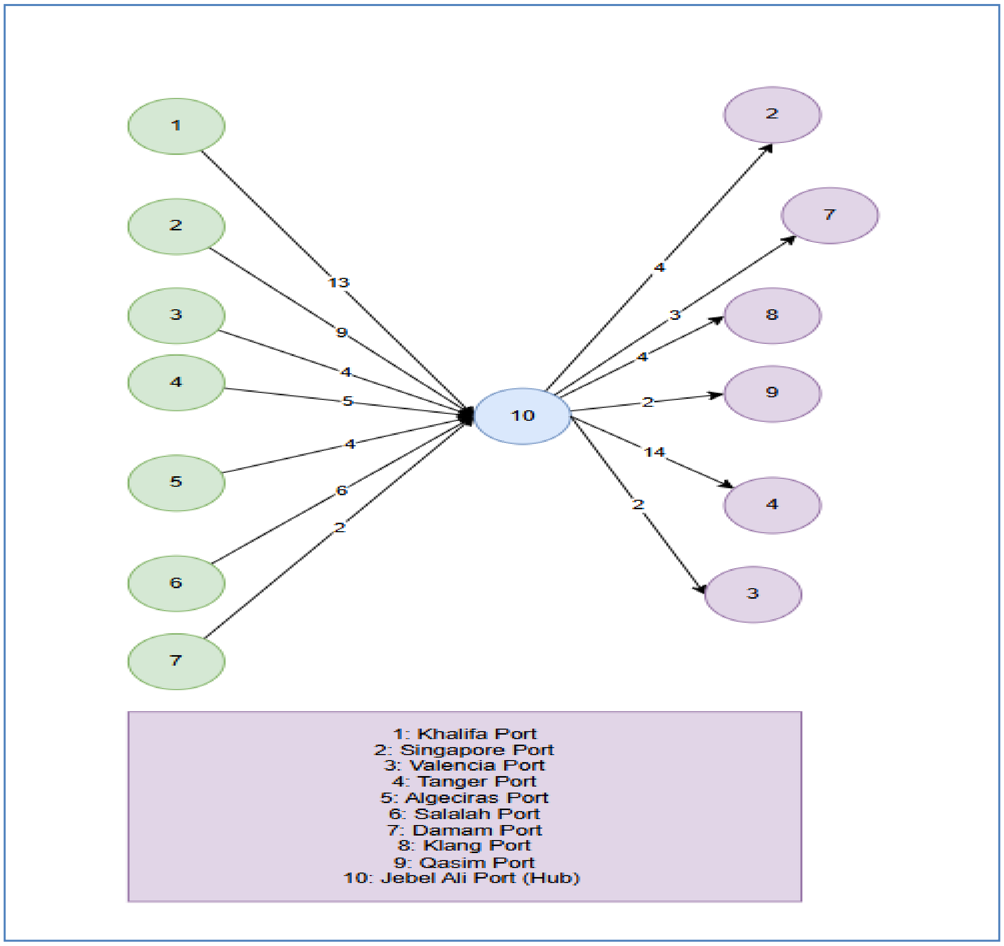

Figure 6. Distribution of Transit Container Vessels Fuel cost via Jebel Ali Seaport

Table 3 below shows another feasible solution for the total fuel consumption in (HFO.Tons) = 1,004,669 Tons to connect the spoke seaports via Jubail Port.

Table 3. Total Fuel Cost for Transit Vessels through Jubail Port

Origin	Destination 11	Duration	Consumption per day in Tons	Total Fuel Consumption in Ton	Supply	Demand
1	149	0.4	1,374	549.6	13	
2	4,272	12.7	1,374	17,449.8	9	4
3	5,386	16	1,374	21,984	4	2
4	5,721	17	1,374	23,358	5	14
5	5,692	16.9	1,374	23,220.6	4	
6	28	0.1	1,374	137.4	6	
7	1,314	3.9	1,374	5,358.6	2	3
8	4,042	12	1,374	16,488		4
9	1,042	3.1	1,374	4,259.4		2
Supply Total Fuel Consumption (HFO.Tons)						473,343

Demand Total Fuel Consumption (HFO.Tons)	531,325.8
Total Fuel Consumption (HFO.Tons)	1,004,669

Table 4 below shows another feasible solution for the total fuel consumption in (HFO.Tons) = 906,290.4 Tons to connect the spoke seaports via Jeddah Islamic Port.

Table 4. Total Fuel Cost for Transit Vessels through Jeddah Islamic Port

Origin	Destination	Duration	Consumption per day in Tons	Total Fuel Consumption in Ton	Supply	Demand
	12					
1	2,373	7.1	1,374	9,755.4	13	
2	4,685	13.9	1,374	19,098.6	9	4
3	2,700	8	1,374	10,992	4	2
4	3,035	9	1,374	12,366	5	14
5	3,006	8.9	1,374	12,228.6	4	
6	1,372	4.1	1,374	5,633.4	6	
7	2,680	8	1,374	10,992	2	3
8	4,455	13.3	1,374	18,274.2		4
9	2,399	7.1	1,374	9,755.4		2
Supply Total Fuel Consumption (HFO.Tons)						509,204.4
Demand Total Fuel Consumption (HFO.Tons)						397,086
Total Fuel Consumption (HFO.Tons)						906,290.4

Table 5 below shows another feasible solution for the total fuel consumption in (HFO.Tons) = 1,044,927 Tons to connect the spoke seaports via Dammam Port.

Table 5. Total Fuel Cost for Transit Vessels through Dammam Port

Origin	Destination	Duration	Consumption per day in Tons	Total Fuel Consumption in Ton	Supply	Demand
	7					
1	121	0.4	1,374	549.6	13	
2	4,266	12.7	1,374	17,449.8	9	4
3	5,380	16	1,374	21,984	4	2
4	5,715	17	1,374	23,358	5	14
5	1,307	3.9	1,374	5,358.6	4	
6	5,685	16.9	1,374	23,220.6	6	
7	0	0	1,374	0	2	3
8	4,036	12	1,374	16,488		4
9	1,041	3.1	1,374	4,259.4		2
Supply Total Fuel Consumption (HFO.Tons)						529,677
Demand Total Fuel Consumption (HFO.Tons)						515,250
Total Fuel Consumption (HFO.Tons)						1,044,927

The basic feasible solutions for the connections of spoke seaports through alternative hub seaports, shows that the best alternative connection is via the Jeddah Islamic Port with total fuel consumption (HFO) of 906,290.4 Tons. See Figure 7.

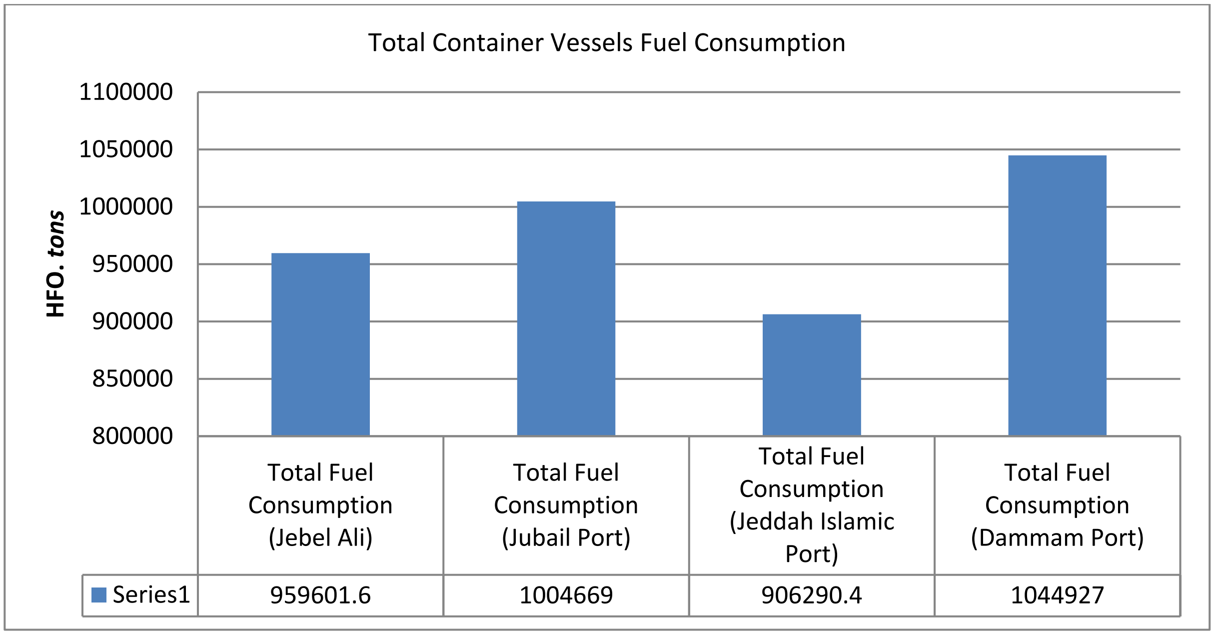

Figure 7. Distribution of Total Fuel Costs via alternative hub settings

c) Building the Transportation table: the transportation table includes the spoke seaports with a direct connection and a supply/demand for each spoke seaport. The total demand equals 29 container vessels, while the total supply equals 43 container vessels. The balance shows that Khalifa port supply of 13 container vessels acts as a buffer seaport for Jebel Ali port. See Table 6.

Table 6. Transportation Table connecting 9 spoke seaports

Origin/Destination	1	2	3	4	5	6	7	8	9	Supply
1										13
2										9
3										4
4										5
5										4
6										6
7										2
8										
9										
Demand		4	2	14			3	4	2	
Total Demand								29		
Total Supply								43		
Dummy Destination								14		

d) Balance between the total supply and the total demand: a dummy destination is being added to balance the total demand with total supply (Table 7).

Total dummy destination capacity = $\sum_{i=1}^{9} a_i - \sum_{j=1}^{9} b_j = 43 - 29 = 14$

Table 7. Balancing the Total Supply with the Total Demand for a set of spoke seaports.

Origin/Destination	1	2	3	4	5	6	7	8	9	Dummy Destination	Supply
1											13
2											9
3											4
4											5
5											4
6											6
7											2
8											
9											
Demand		4	2	14			3	4	2	14	

e) Introducing the Hub seaports: the first attempt is to consider Dammam, Jubail and Jeddah Seaports as hub transit seaports. The capacities of the hub transit seaports $=\sum_{i=1}^{9} a_i = \sum_{j=1}^{9} b_j$. The total capacities equals:

- Jubail Supply/Demand=43
- Jeddah Islamic Port Supply/Demand=43
- Dammam Port Supply=43+a_i=43+2=45
- Dammam Port Supply=43+b_j=43+3=46

The cost of shipping (Fuel Consumption in tons) is shown in the table 8 between the spoke seaports and the hubs ports (Table 8 and Table 9).

Table 8. Adding Tansit Sea ports as a Supply and Demand Nodes.

O /D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**D. D**	**11**	**12**	**S.**
1							549.6				549.6	9,755.4	13
2							17,449.8				17,449.8	19,098.6	9
3							21,984				21,984	10,992	4
4							23,358				23,358	12,366	5
5							5,358.6				23,220.6	12,228.6	4
6							23,220.6				137.4	5,633.4	6
7	549.6	17,449.8	21,984	23,358	5,358.6	23,220.6	M	16,488	4,259.4		5,358.6	10,992	45
8							16,488				16,488	18,274.2	
9							4,259.4				4,259.4	9,755.4	
11	549.6	17,449.8	21,984	23,358	23,220.6	137.4	5,358.6	16,488	4,259.4				43
12	9,755.4	19,098.6	10,992	12,366	12,228.6	5,633.4	10,992	18,274.2	9,755.4				43
D.		4	2	14			46	4	2	14	43	43	

1- Restrict the direct ravel between movement spoke seaports: assigning a big number (M=100,000) for direct shipments between the same node, the travelling between two spoke seaports.

Table 9. Assigning Costs for the Transportation Table.

O /D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**D. D**	**11**	**12**	**S.**
1	M	M	M	M	M	M	549.6	M	M	0	549.6	9,755.4	13
2	M	M	M	M	M	M	17,449.8	M	M	0	17,449.8	19,098.6	9
3	M	M	M	M	M	M	21,984	M	M	0	21,984	10,992	4
4	M	M	M	M	M	M	23,358	M	M	0	23,358	12,366	5
5	M	M	M	M	M	M	5,358.6	M	M	0	23,220.6	12,228.6	4
6	M	M	M	M	M	M	23,220.6	M	M	0	137.4	5,633.4	6
7	549.6	17,449.8	21,984	23,358	5,358.6	23,220.6	M	16,488	4,259.4	0	5,358.6	10,992	45
8	M	M	M	M	M	M	16,488	M	M	0	16,488	18,274.2	
9	M	M	M	M	M	M	4,259.4	M	M	0	4,259.4	9,755.4	
11	549.6	17,449.8	21,984	23,358	23,220.6	137.4	5,358.6	16,488	4,259.4	0	M	M	43
12	9,755.4	19,098.6	10,992	12,366	12,228.6	5,633.4	10,992	18,274.2	9,755.4	0	M	M	43
D.		4	2	14			46	4	2	14	43	43	

f) Generating the solution: Microsoft Excel Solver is used to generate the solution (Table 10). The optimal fuel consumption to connect the spoke seaports via the suggested Saudi seaports equals 1,320,689 Tons. Table 11 shows the number of travelling vessels through the seaports.

Table 10. Optimum Number of Container Vessels Distributed Among the Transit Shipping Routes

O /D	1	2	3	4	5	6	7	8	9	Dummy Destination	11	12	S.
1	0	0	0	0	0	0	0	0	0	0	13	0	13
2	0	0	0	0	0	0	0	0	0	0	0	9	9
3	0	0	0	0	0	0	0	0	0	0	0	4	4
4	0	0	0	0	0	0	0	0	0	0	0	5	5
5	0	0	0	0	0	0	0	0	0	0	0	4	4
6	0	0	0	0	0	0	0	0	0	0	0	6	6
7	0	0	0	0	0	0	0	0	0	0	30	15	45
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	43	0	0	0	0	0	43
12	0	4	2	14	0	0	3	4	2	14	0	0	43
D.		4	2	14			46	4	2	14	43	43	

g) Buffer computation: In this step we need to allocate a sufficient space at each transit (hub) Sea port for Figure 8 below shows that 13 container vessels are routed from seaport 1 to 11, 9 container vessels are routed between seaport 2 and 12, 4 container vessels are routed between seaport 3 and 12, 5 container vessels are routed between seaport 4 and 12, 4 container vessels are routed between seaport 5 and 12, 6 container vessels are routed between seaport 6 and 12. 43 container vessels are routed between seaport 11 and 7, 30 container vessels are routed between seaport 7 and 11, 15 container vessels are routed between seaport 7 and 12, 3 container vessels are routed between seaport 12 and 7. 4 container vessels are routed between seaport 12 and 8, 2 container vessels are routed between seaport 12 and 9, 14 container vessels are routed between seaport 12 and 4, 2 container vessels are routed between seaport 12 and 3, 4 container vessels are routed between seaport 12 and 2, and 14 container vessels are routed between seaport 12 and D.D. (Dummy Destination).

h)

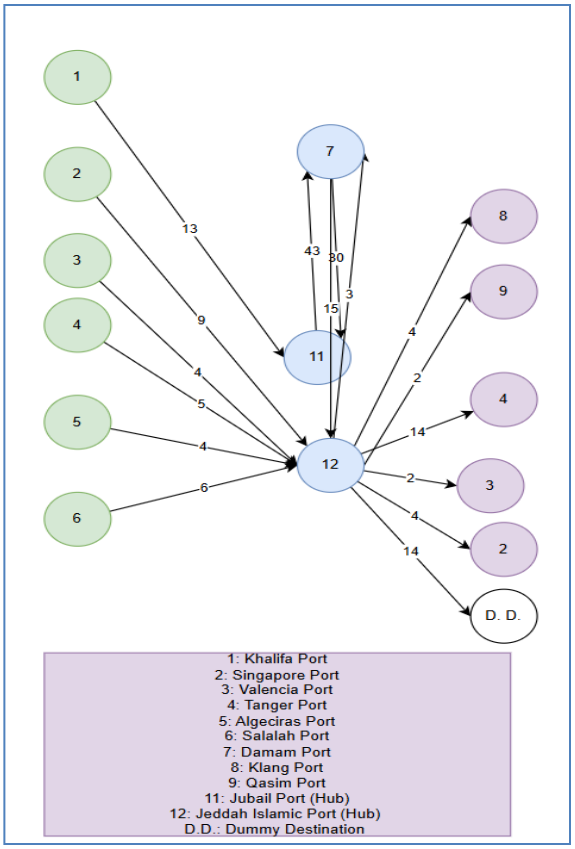

Figure 8. Optimum Distribution of Transit Container Vessels via Saudi Seaports

i) Verifying the results: Tora Optimization application for windows was used to verify the results. The optimal solution match with Microsoft Excel Solver results. The optimal value equals 1,320,688.8 Tons. Each ton of HFO is equivalent to 42 Tera Joule. The Optimized energy consumed is equal to (1,320,688.8×42=55,468,929.6 Tera Joule).

j) Modeling and Simulation: The container vessel Arrives to the arrival station at SAJED Port (Jeddah Islamic Port), then the container vessel is routed to the Terminal align station, container vessels arrive and is sent to either Terminal 1 or Terminal 2 depending on availability, otherwise the vessel will queue. Once the container vessel is routed to the Terminal Station, the loading and unloading activities are performed, once finished the vessel leaves the port by routing it to the departure Station, the times for inter-arrivals are analyzed based on the arrivals to Jebel Ali port and the service times are for data analysis on SAJED port. Figure 9 shows the logic at SAJED port.

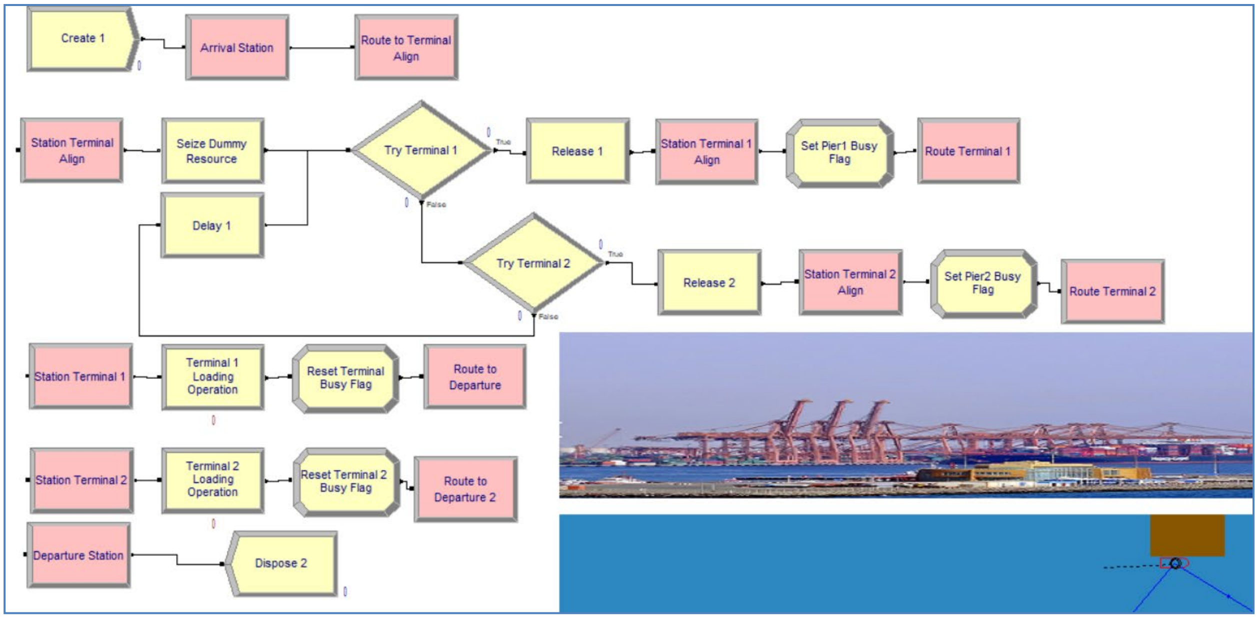

Figure 9. Logic for Container vessels flow at Jeddah Islamic Port (SAJED)

The data for inter-arrivals to Jebel Ali port are shown below (See Table 11), for container vessel with gross tonnage between 80k - 200k Tons. The analysis of data is made through Arena input analyzer and the fitted model is shown in Figure 10.

Table 11. Time Between Arrivals at the Benchmark Port (Jebel Ali)

ID	Arrivals	Time between arrivals at Jebel Ali Port (Days)	Hours
1	5/13/2024 0:27		
2	5/13/2024 11:30	0.460417	11.05
3	5/14/2024 1.27	0.58125	13.95
4	5/15/2024 0:56	0.978472	23.48333
5	5/15/2024 17.23	0.685417	16.45
6	5/16/2024 3:52	0.436806	10.48333
7	5/18/2024 11:04	2.3	55.2
8	5/19/2024 6:21	0.803472	19.28333
9	5/20/2024 1:24	0.79375	19.05
10	5/20/2024 14:29	0.545139	13.08333
11	5/20/2024 17:47	0.1375	3.3
12	5/22/2024 1:18	1.313194	31.51667
13	5/22/2024 17:05	0.657639	15.78333
14	5/23/2024 11:00	0.746528	17.91667
15	5/23/2024 14:58	0.165278	3.966667
16	5/23/2024 18:29	0.146528	3.516667

17	5/24/2024 5:30	0.459028	11.01667
18	5/24/2024 11:43	0.259028	6.216667
19	5/25/2024 4:52	0.714583	17.15
20	5/25/2024 11:30	0.276389	6.633333
21	5/28/2024 0:18	2.533333	60.8
22	5/28/2024 0:56	0.026389	0.633333
23	5/28/2024 10:15	0.388194	9.316667
24	5/29/2024 11:28	1.050694	25.21667
25	5/30/2024 10:26	0.956944	22.96667
26	5/30/2024 14:56	0.1875	4.5
27	5/31/2024 10:02	0.795833	19.1
28	6/2/2024 3:31	1.728472	41.48333
29	6/2/2024 12:03	0.355556	8.533333
30	6/3/2024 0:45	0.529167	12.7
31	6/4/2024 22:23	1.901389	45.63333
32	6/5/2024 16:07	0.738889	17.73333
33	6/6/2024 12:12	0.836806	20.08333
34	6/6/2024 18:00	0.241667	5.8
35	6/6/2024 23:48	0.241667	5.8
36	6/8/2024 0:28	1.027778	24.66667
37	6/8/2024 7:05	0.275694	6.616667
38	6/8/2024 8:14	0.047917	1.15
39	6/10/2024 3:48	1.815278	43.56667
40	6/11/2024 2:37	0.950694	22.81667

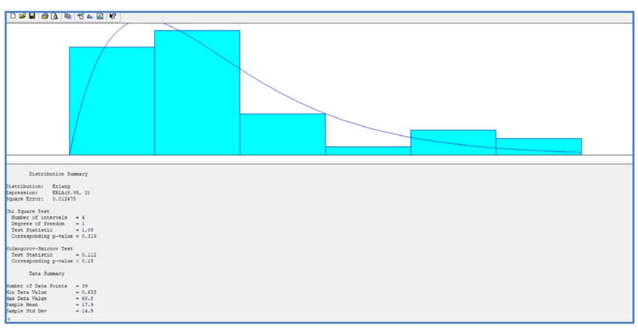

Figure 10. Output Screen of Arena Input Analyzer Analysis of Inter-arrival times at the Benchmarked Port

Table 12 shows the Distribution summary fitted for the inter-arrival times at Jebel Ali Port.

Table 12. Distribution Summary of the Container Vessels Inter-arrivals at the Benchmarked Port (Jebel Ali)

Distribution Summary	
Distribution:	Erlang
Expression:	ERLA(8.95, 2)

Square Error:	0.012478
Chi Square Test	
Number of intervals	4
Degrees of freedom	1
Test Statistic	1.08
Corresponding p-value	0.319
Kolmogorov-Smirnov Test	
Test Statistic	0.112
Corresponding p-value	> 0.15
	Data Summary
Number of Data Points	39
Min Data Value	0.633
Max Data Value	60.8
Sample Mean	17.9
Sample Std Dev	14.5
	Histogram Summary
Histogram Range	= 0 to 61
Number of Intervals	6

The analysis of service times at SAJED is for the same container vessels capacities (80 K- 200 K tons) for the same duration, 30 days and similar time interval. The service times for container vessels are shown in Table 13, while Figure 11 shows the output of Arena Rockwell Input analyzer.

Table 13. Service Times For a Number of ContainerVessels in Jeddah Islamic Port (SAJED) Port

Container Vessel Arrival	**Container Vessel Departure**	**Service Time (Days)**	**Service Time (Hours)**
5/17/24 10:43	5/18/2024 17:49	1.295833	31.1
5/18/2024 8:00	5/19/2024 12:31	1.188194	28.51667
5/24/2024 7:29	5/25/2024 1:45	0.761111	18.26667
5/24/2024 10:38	5/25/2024 23:15	1.525694	36.61667
5/25/2024 7:12	5/26/2024 11:58	1.198611	28.76667
5/26/2024 11:03	5/27/2024 7:36	0.85625	20.55
5/31/2024 0:20	6/1/2024 3:02	1.1125	26.7
5/31/2024 13:16	6/2/2024 3:30	1.593056	38.23333
6/2/2024 10:24	6/2/2024 20:05	0.403472	9.683333
6/4/2024 6:59	6/5/2024 12:05	1.2125	29.1

6/5/2024 12:28	6/6/2024 8:44	0.844444	20.26667
6/6/2024 10:05	6/7/2024 4:37	0.772222	18.53333
6/6/2024 15:57	6/9/2024 12:31	2.856944	68.56667
6/7/2024 7:05	6/9/2024 13:02	2.247917	53.95

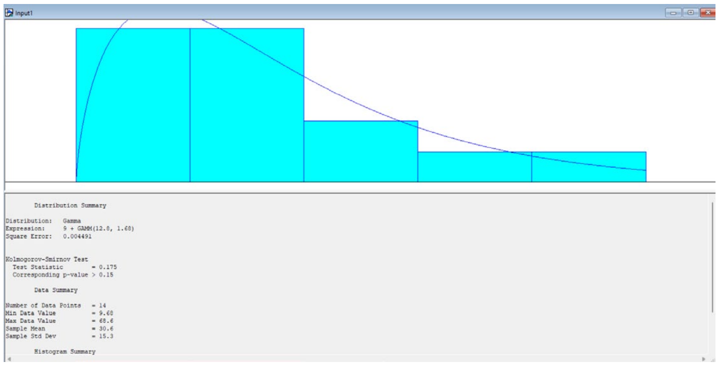

Figure 11. Output Screen of Arena Input Analyzer for the analysis performed on the service times at Jeddah Islamic Port

Table 14 shows the Distribution summary fitted for the service times at SAJED Port.

Table 14. Distribution Summary for the Service Times for Container Vessels at Jeddah Islamic Port (SAJED)

Distribution Summary	
Distribution:	Gamma
Expression:	9 + GAMM(12.8, 1.68)
Square Error:	0.004491
Kolmogorov-Smirnov Test	
Test Statistic	0.175
Corresponding p-value	> 0.15
	Data Summary
Number of Data Points	14
Min Data Value	9.68
Max Data Value	68.6
Sample Mean	30.6
Sample Std Dev	15.3
	Histogram Summary

Histogram Range	= 9 to 69
Number of Intervals	5

Figure 12 presents the run of the loading and unloading activities logic at SAJED port.

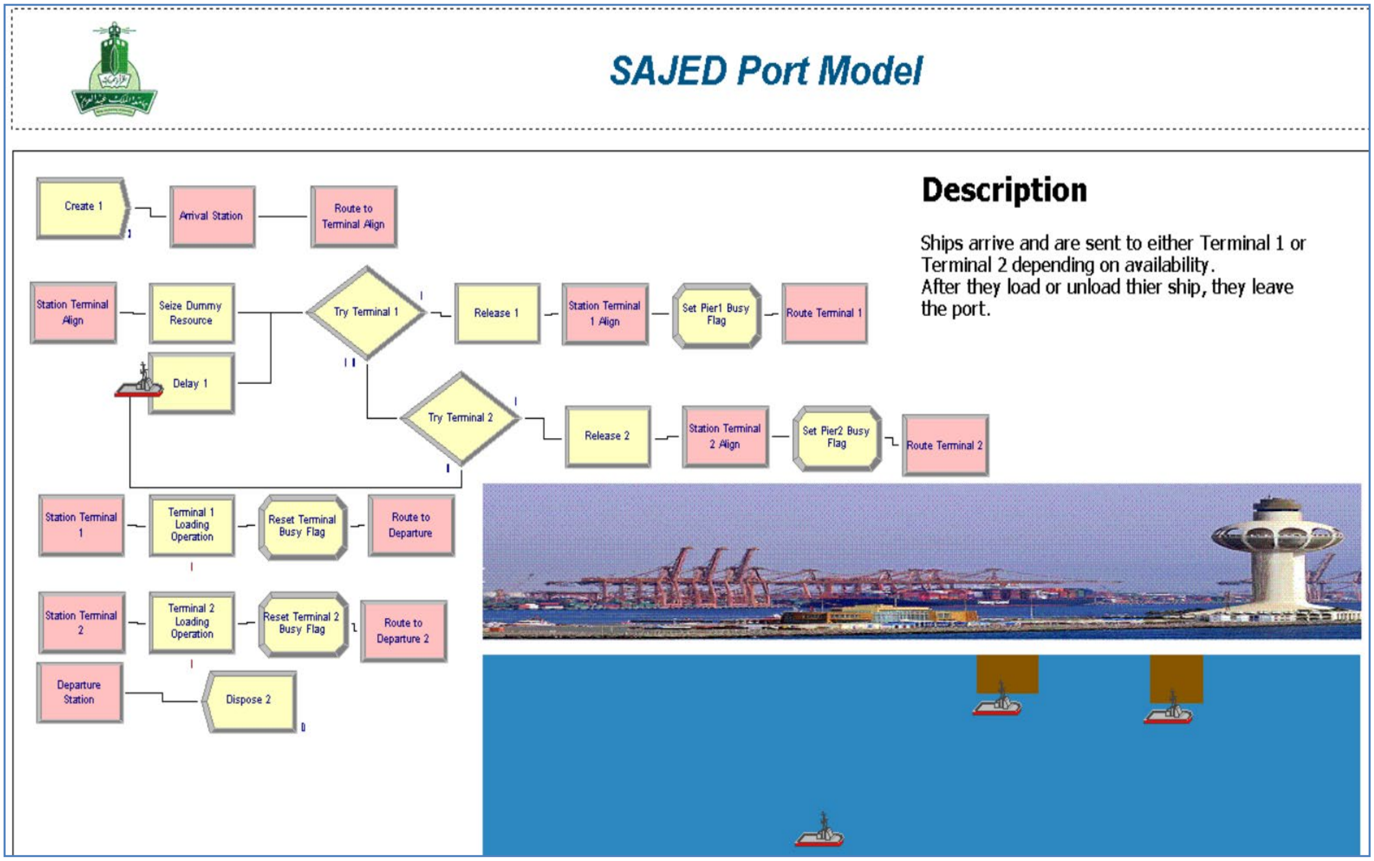

Figure 12. Run of the Model for One Month Duration

The output of Arena simulation model of a 1 month duration shows that the expected number of container vessels entering to the port is 40 container vessels in a month, of which it is expected to have 35 vessels serviced.

The analysis of the data shows that at any time, the expected number of container vessels waiting in the process is equal to 2.5 vessels, a minimum value of 0 and a maximum of 6 vessels. The estimated total time spent by a container vessel at SAJED port equals to 48.79 hours with a minimum value of 12.59 hours up to 98 hours. The expected service time of loading and unloading activities equals to 33.93 hours, while, the waiting time is expected to be 14.85 hours before starting routing the vessel from the arrival station. The results also show that the loading and unloading activities may take 12.59 hours (Min.) and a (max. of 98 hours). The total service time at Terminal 1 is equal to 613.37 hours and the total service time for Terminal 2 is 574.52 hours. The expected number of serviced vessels at Terminal 1 equals to 18 container vessels and 17 container vessels at Terminal 2. The utilization of Terminal 1 equals to 86.74% and 82.51% for Terminal 2.

As of the simulation model results, the Average time spent by a container a vessel at SAJED port equals to 48.79 hours, of which 14.86 hours waiting for service, and 33.93 hours for service time. While comparing the results to the benchmark (Jebel Ali Port) and Ports in UAE, according to Statistical analysis, the average time spent in UAE Ports is 1 day. The total spent time of 1 day at Jebel Ali port is half the time spent by a Container vessel in SAJED Port. Where;

$$W_s: waiting\ time\ in\ the\ system$$
$$W_p: waiting\ time\ in\ the\ process$$
$$W_q: waiting\ time\ in\ the\ queue$$

The total time spent in Jeddah Port is being formulated by the following notations:

$$W_s = W_P + W_q \ldots (7)$$

The service time in Jeddah port (W_p) = 33.93 hours and is greater than (W_s) Jebel Ali =24 hours. This shows the need for re-innovating the port in Jeddah, with a double sized expansion.

4. Results, Conclusions and Recommendations

4.1 Conclusions

This paper stated that the main problem is that due to economic competition among countries and that the sea ports are a key factor in the economic growth, and that due to closing of some seaports due to bad economic conditions, this paper tries to motivate the transshipment of container vessels through Saudi Arabian ports instead of "Jebel Ali port" (One of the 10 most transit ports). This study tries to reduce fuel costs using the transshipment model.

Fuel consumption is proportional to the speed of the container vessel. This paper aims to reduce the fuel consumption and re-scheduling traffic at Jebel Ali port to Saudi Arabian ports and try to simulate the results. The modeling and scheduling process of applying the transit model to the Saudi sea ports was tested. The modeled transit network has been simplified into a transportation network in which seaports are interconnected by direct point-to-point connections. The model's objective function is to minimize total fuel burned (MJ) for transporting model container vessels through a simplified route network, the solution of which determines the number of container vessels.

The simulation results shows that the total time spent in Jeddah port by a container vessel is 48.79 hours and it is considered slow double the time spent by a container vessel in Jebel Ali port. To summarize, Seaports are under a high competition due to its importance in the overall economy. Many seaports are under bankruptcy due to negative performance. Industrial Revolution is based on many factors including the availability of a port that is active on the routes of shipping companies. Since then, this paper has developed a hub and spoke optimization model that routes the traffic through Saudi ports rather than Jebel Ali port (one of the top 10 transit points in the world).

4.2 Recommendations and Future Study

This paper recommends the following:

1- Motivating the container vessels to connect through Jeddah Islamic Port by offering a lower HFO rates.
2- Allowing industrial and manufacturing firms to be located beside the port, to allow the assembly of units and re-export the assembled materials.
3- Supporting the national shipping industry by routing their container vessels through SAJED port.
4- Expanding the SAJED sea port.
5- Re-innovating SAJED port.
6- Benchmarking the Japanese sea ports, which is considered the fastest ports in the world?

7- Future studies shall consider the studying of Penalties paid for container vessel shipping companies due to delayed loading and unloading of shipments.

Author Contributions

Conceptualization, M.A.B., and A.Z.H.; literature review, M.A.B., and A.Z.H.; methodology, M.A.B., and A.Z.H.; validation, M.A.B., and A.Z.H.; investigation, M.A.B., and A.Z.H.; resources, M.A.B., and A.Z.H.; data curation, M.A.B., and A.Z.H.; writing—original draft preparation, M.A.B., and A.Z.H.; writing—review and editing, M.A.B., and A.Z.H.; visualization, M.A.B., and A.Z.H.; supervision, M.A.B.., and A.Z.H.; project administration, M.A.B., and A.Z.H.; All authors have read and agreed to the published version of the manuscript." Funding: This research received no external funding. Informed Consent Statement: Not applicable. Data Availability Statement: The data supporting the findings of this study are available within the article.v

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