THE CASPIAN SEA OIL TRANSPORTATION POTENTIALS THROUGH IRANIAN SEAPORTS

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ABSTRACT

In this research, the Caspian Sea oil transportation via Iranian seaports was studied. The Caspian Sea oil transportation is consisted of three stages. The first stage, occurring in the origin seaport, is loading of oil from storage and transportation facilities, to sea tankers. The second stage is the shipment by sea tankers from the origin port to the destination port via the Caspian Sea link. The third stage is unloading of the oil in the destination port to storage and land transportation facilities. The cargo, herein oil, passes through several administrative and physical steps in each of the three stages. Computer models were developed to simulate and predict oil shipment characteristics through the three stages. The developed simulation models were acceptable representations of the involved processes when their modeling could not be more simplified to be amenable to analytical solutions of queuing theory. The models were calibrated, validated and then used for prediction. The efficacy and potentials for Iranian seaports. For efficient Caspian Sea oil transportation and export, the results confirmed the need of further cooperation of involved countries and decision-makers. The developed models can be further used in future Caspian Sea oil and gas transportation analysis and planning.

INTRODUCTION

The Caspian Sea, extending from $36^\circ$ to $54^\circ$, is the largest lake in the world. Its water volume is about 80,000 km$^3$, greatest depth is at 1 km, longest length is at 1200 km, largest width is at 554 km and its average depth is 180 km. Shaped roughly like the letter S, morphologically the Caspian Sea can be divided into three distinct sections: (1) a northern shallow section adjoining the mouths of the Volga and Ural rivers with depths not exceeding 10 m, (2) a middle section with an average depth of about 200 m, (3) a deeper southern section with an average depth of 300 m. The proportional water volumes of the three parts are 1/100, 1/3, and 2/3 respectively. The salinity of the water ranges from 0.2 g/l at the mouth of the Volga to 13 g/l in the south part. Five countries namely, Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan surround the lake. The Caspian Sea plays a crucial role in the interactions between its surrounding countries as well as being a vital natural resource for them. The recent Caspian Sea oil exploration activities have shown very promising gas reserves of around 30 trillion m$^3$ and oil reserves of around 30 billion barrels [6,12].

The Caspian Sea provides marine access to the surrounding countries, and is connected to Baltic Sea and Black Sea via Volga and Done rivers. The Caspian Sea
principal seaports are: Baku in Azerbaijan, Astrakhan and Makhachkala in Russia, Aktau in Kazakhstan, Turkmenbashi (Krasnovodsk) in Turkmenistan, Anzali, Noshahr and Neka in Iran. The important commodity carried by Caspian ships has been petroleum. Until World War II, crude oil, the Caspian tankers were mostly engaged in carrying crude oil and refined products from Baku and Makhachkala to Astrakhan, where they were transshipped to Volga river tankers for the industrial oil consumers of European Russia. After the World War II and until the formation of the Commonwealth of Independent States (CIS), Baku, Astrakhan and Krasnovodsk handled more Caspian Sea traffic than the other ports. A new era of the Caspian Sea navigation and marine activities started after the disintegration of Soviet Union. Without its past major rule of planning and controlling of the Caspian Sea traffic, Russia remained as the major transportation fleet owner. The Caspian Sea fleet and port characteristics are summarized in Table 1. The ships are those above 1000 dwt and the ports are suitable for drafts of up to 6 m [4,5].

Table 1. The Caspian Sea port and sea fleet characteristics

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of ships</th>
<th>Ports</th>
<th>No. of berths</th>
<th>No. of cranes</th>
<th>Pipe</th>
<th>Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azerbaijan</td>
<td>75</td>
<td>Baku</td>
<td>11</td>
<td>18</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Iran</td>
<td>4</td>
<td>Anzali</td>
<td>5</td>
<td>6</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Noshahr</td>
<td>5</td>
<td>2</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neka</td>
<td>3</td>
<td>0</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>0</td>
<td>Aktau</td>
<td>12</td>
<td>6</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Russia</td>
<td>2000</td>
<td>Astrakhan</td>
<td>20</td>
<td>40</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Makhachkala</td>
<td>2</td>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>4</td>
<td>Turkmenbashi</td>
<td>6</td>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The first decade of this era has been an evolving political and economical period for the riparian countries with massive oil and gas exploration activities. During this decade, the demand for water transportation has been very sensitive to political and economical changes. This has resulted in a very fluctuating and in-equilibrium water transportation pattern for the Caspian Sea. The Anzali port, for example, handled more Caspian Sea traffic in 1997 than other ports. Nevertheless, the water transportation supply and demand potentials have encouraged the riparian countries to invest in their seaport facilities. To play a more active role in Caspian Sea economical and commercial activities, Iran has been
developing its seaports to reach to a capacity of more than 10 million tons per year by the beginning of new millennium.

To study Iranian seaports oil transportation characteristics and potentials, relevant data were collected. The research database consisted of oil transportation demand and supply information. Figure 1 shows the Caspian Sea and all its major seaports. Computer models were developed to simulate oil loading, shipment and unloading characteristics. The developed simulation models were acceptable representations of the involved processes. The developed models can be used in Caspian Sea transportation analysis and planning [1-3,8-10,13,14].

DATABASE AND STUDY SCOPE

Due to limited study resources, only three months of petroleum sea transportation demand and supply information for Iranian seaports was gathered. The relevant data were extracted from field survey and observation, port authority and shipping agency databanks. Information covered the period of March to June 1998, and included all petroleum shipments from Baku, Makhachkala, Astrakhan, Aktau and Turkmenbashi to Iranian seaports. There was no reported oil export, cobatage or transship from Iranian ports during this period.

In the chain of all involved processes and transportation networks connecting crude oil from original underground reservoirs to final consumers as refined oil products, only the sections occurring in the seaports and the Caspian Sea were studied. This portion consisted of three stages and is shown in Figure 2. The first stage, occurring in the origin seaport, is loading of oil from storage facilities, pipelines, highway tankers, railway tankers and offshore oil facilities to sea tankers. The second stage is the shipment by sea tankers from the origin port to the destination port via the Caspian Sea link. The third stage is unloading of the oil in the destination port to storage facilities, pipelines, highway tankers and railway tankers. The oil cargo passes through several administrative and physical steps in each of the three stages.

The demand information extracted from published reports was consisted of origin-destination information of oil cargo for sea transportation and is often called cargo data. The demand is unstable and sensitive to political, commercial and economical interactions of riparian countries. The supply information gathered from field survey and databanks was consisted of infrastructure, equipment, service and operational characteristics of the seaport most sensitive to demand attributes. The supply characteristics are time-related ship transportation and traffic data, port equipment and facility data, port manpower and labor data.

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Oil     Processses  Caspian Sea    Processes  Destination port Oil
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197
To develop descriptive mathematical model of Caspian Sea oil transportation, there were two candidate techniques, namely analytical models and simulation models. To use the analytical models, the system representation should be so simplified that can be readily solved by queuing theory. In this technique, many assumptions are made so that the relations among system components become very simple. Furthermore, the interarrival and service times of various components should be simplified and be presented by specific probability distribution functions. The study of complex systems that cannot be simplified to be amenable to analytical queuing models, requires simulation models to derive numerical solutions. A simulation model is an abstraction of real system so that its essential aspects are retained in the model. The model can be used either to enhance the understanding of how the system works or to investigate the potential effects of system changes.

Due to complexity of the Caspian Sea oil transportation operations, simulation modeling was used. Due to limited study resources, it was not possible to prepare and write the software. Among the available simulation software, the personal computer versions of Slam and Taylor were evaluated. The Taylor was found more flexible and adaptable for this research. The software is widely used by planners and engineers. It has visual and object oriented programming capabilities. To model Caspian Sea oil transportation, a network of program elements such as Inout, Buffer, Machine, Warehouse, Transporter and Conveyor were created and connected. The details of the developed models are too lengthy and extensive to be explained in this paper. The developed models can be used to simulate oil shipment between any pair of seaports.

The cargo, herein oil, passes through several port and sea transportation processes summarized by 23 blocks of Figure 3. In the developed models, each block was presented by one or more of Taylor program elements. Blocks 1 to 9 occur in the origin port and present the first stage of Figure 2. Blocks 10 to 15 occur in the Caspian Sea and present the second stage of Figure 2. Blocks 16 to 23 occur in the destination port and present the third stage of Figure 2. The cargo, can be stored in storage facilities at the origin port or/and the presented by possibility of cargo going from block 2 either to blocks 3 or 7. At the destination port, this is presented by possibility of cargo going from block 16 either to blocks 17 or 21. For the period of analysis, the amount of stored petroleum is less than ten percent. The and after their unloading at the destination ports. The models have the capabilities of simulating the situations that loading are also occurring in the destination ports and oil shippings are also occurring in the way back to the origin ports. These did not occur in the observed oil import and transit to Iranian seaports. The details for each block are too lengthy and extensive to be explained in this paper.

The model input information is demand and supply data. The demand information is consisted of origin-destination information of petroleum sea transportation. Table 2 presents the 1998 import and transit estimates for Iranian ports. These rather rough estimates are based on 3 months of cargo data for oil shipment. As mentioned before, they are sensitive to evolving commercial, economical and political processes of the regional.
Figure 3. Simulation model of Caspian Sea oil transportation
Table 2. The oil shipment estimates for Iranian seaports in thousand tons

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Astrakhan</th>
<th>Baku</th>
<th>Turkmenbashi</th>
<th>Aktau</th>
<th>Makhachkala</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anzali</td>
<td>950</td>
<td>182</td>
<td>625</td>
<td>143</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Noshahr</td>
<td>556</td>
<td>18</td>
<td>292</td>
<td>246</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Neka</td>
<td>325</td>
<td>0</td>
<td>63</td>
<td>262</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1831</td>
<td>200</td>
<td>980</td>
<td>651</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The supply information is consisted of service and operational characteristics of the seaport and transportation facilities. Indeed each block of Figure 3 shows one or more processes that have been characterized by some time-related parameters and relations for a pair of seaports. The details are too extensive to be explained herein, only a few examples are discussed. For example for Anzali seaport, headway of ship arrival data showed a negative exponential probability density function with a mean of 17.35 hours. The ship cargo weight data showed a lognormal probability density function with a mean of 4498.3 tons and of standard deviation 459.7 tons. The highway tanker weight data showed a normal distribution with a mean of 22.5 tons and of a standard deviation 2.6 tons. The duration of highway tanker oil loading to and unloading from the ships showed a normal probability density function with a mean of 4 minutes and a standard deviation of 1.5 minutes. The duration for a ship to leave or arrive at a berth showed a normal probability density function with a mean of 50 minutes and a standard deviation of 25 minutes. Based on reported data, relations and statistical parameters for the 23 blocks of Figure 3 were assessed and estimated. For practical application of the developed models, estimates should be further improved by future comprehensive, continuing, cooperative and consistent data collection and reporting.

With the aforesaid demand and supply information, the oil transportation to Iranian seaports was simulated. The model outputs consisted of time-related information of efficacy and operations at each stage and its substages. The model outputs consisted of information such as waiting times, occupancy ratios, service and transportation times, facility utilization 3 summarizes the results of the simulation runs for the year 1998. The listed oil transportation duration is the sum of durations at the origin seaport, the Caspian Sea and the destination seaport. The average utilization for the three stages is less than fifty percent, reflecting that the shipment can be doubled without significant duration increase. Post modeling analysis consisted of sensitivity analysis. The effects of the demand and/or supply model input changes on oil transportation duration were investigated. The details of sensitivity analysis are too lengthy and extensive to be reported herein. The analysis showed
the changes of waiting times, occupancy ratios, service and transportation times, facility utilization and queue lengths with respect to each input parameter change. For example, the sensitivity analysis showed that the increase of oil shipment or demand to Anzali seaport up to twice of its current figures would not significantly change the destination seaport duration. Sensitivity analysis showed that cooperation of involved operators and decision-makers are essential in efficient oil shipment through a chain of interrelated activities. Sensitivity analysis further confirmed that inefficient operation in a single block of Figure 3 can result in significant delays.

Table 3. Oil transportation duration from origin ports to destination ports in hour

<table>
<thead>
<tr>
<th>Port</th>
<th>Anzali</th>
<th>Noshahr</th>
<th>Neka</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astrakhan</td>
<td>111</td>
<td>109</td>
<td>n/a</td>
<td>110</td>
</tr>
<tr>
<td>Baku</td>
<td>79</td>
<td>61</td>
<td>51</td>
<td>64</td>
</tr>
<tr>
<td>Turkmenbashi</td>
<td>65</td>
<td>57</td>
<td>38</td>
<td>54</td>
</tr>
<tr>
<td>Average</td>
<td>85</td>
<td>76</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSIONS

In this research, the Caspian Sea oil transportation via Iranian seaports was characterized and modeled. The computer models were developed to simulate and predict oil shipment. The simulation models were calibrated, validated and then used for prediction. For refinement of the developed models, parameter estimates should be further improved by future comprehensive, continuing, cooperative and consistent data collection and reporting. Nevertheless, the developed models are capable of evaluating and assessing different sensitivity analysis showed the Caspian Sea oil transportation efficacy and potentials for Iranian seaports. For efficient oil transportation and export, the results confirmed the need of further cooperation and coordination among involved operators and decision-makers. Only cooperation of involved countries and decision-makers can make this to happen. An inappropriate or inefficient operation in a single stage of the involved interrelated stages can result in significant oil shipment delays. The developed models can be further used in future Caspian Sea oil and gas transportation analysis and bottleneck identification. Nevertheless, complete in-house made models are more promising. To take the initiative, cooperation of determine characteristics such as the costs, prices, resource requirements and impacts of the involved processes of oil shipment.

ACKNOWLEDGMENTS
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