Belgian Journal of Operations Research, Statistics and Computer Science Vol. 40 (3-4) 00

Design of a Sea-Borne System for Fresh Water Transport - A Simulation Analysis

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Abstract

This paper describes a real problem faced by a major international shipping company regarding the design of a sea-borne system for fresh water transport from Turkey to Jordan in the Middle East. The fresh water was to be transported with high regularity at sea from Turkey to discharging buoy(s) by the coast in Israel, then in pipeline(s) from the buoy(s) to a tank terminal ashore and finally through pipeline from Israel to Jordan. The analysis aimed at answering questions regarding the needed number, capacity and speed of vessels, capacity and number of discharging buoys, design and capacity of pipelines and necessary capacity of the tank terminal. Another crucial question was how sensible the chain was to failures of each component in the chain like the ships or loading/unloading buoys.

To answer these questions, a simulation model was developed and simulations were run for a number of scenarios. Based on this analysis, the shipping company was able to reveal where bottlenecks arose when the capacities of the different parts in the transport chain were changed. Hence, the simulation analysis was used as a decision support in designing an optimal transport system.

Keywords: transport system design, simulation, sea transport, decision support

1 INTRODUCTION

This paper describes a real problem faced by a major international shipping company regarding the design of a sea-borne system for fresh water transport from Turkey to Jordan in the Middle East. At the time of the study, the shipping company experienced that their single-hull crude oil tankers could not be used in the oil tanker trade any longer. This was a result of the introduction of international rules restricting the use of such single-hull vessels in this trade due the risk of oil emissions. Therefore, the shipping company had to find an alternative use for these vessels and they wanted to study the opportunities for the fresh water transport.

The fresh water should be transported with high regularity and robustness at sea from Turkey to discharging buoy(s) by the coast in Israel, then in pipeline(s) from the buoy(s) to a tank terminal ashore and finally through pipeline from Israel to Jordan. The shipping company wanted to examine the system design, particularly regarding the regularity and robustness requirements. The study aimed at answering questions on the transport chain, such as the required number, capacity and speed of vessels, capacity and number of discharging buoys, design and capacity of pipelines and necessary capacity of the tank terminal. Another crucial question was how sensible the chain was to failures of each component in the chain like the ships or loading/unloading buoys.

To answer such questions, a simulation model was developed and simulations were run for a number of scenarios. Based on this analysis, the shipping company was able to reveal where bottlenecks arose when the capacities of the different parts in the transport chain were changed. Hence, the simulation analysis could be used as a decision support in designing an optimal transport system.

The design of a transport system is an important strategic issue that often involves extensive investments. Therefore, thorough studies and analyses are important to obtain a good support for decision-making. In the Operational Research literature, a few references to research and case studies exist on the design of sea-borne transport systems.

Etezadi and Beasley (1983) distinguish between fleet size and fleet composition problems. Fleet size problems deal with deciding the type of vessels and the number of each type when the optional vessel types are given. Fleet composition problems consider the determination of both the type to operate and the number of each type. The pioneer work of Dantzig and Fulkerson (1954), which is to minimise the number of tankers to meet a fixed schedule, can be considered as a vessel fleet size problem, in which there is only one type of vessel available. Jaikumar and Solomon (1987) also consider a fleet size problem with only one type of vessel. The objective here is to minimise the number of barges between different ports in a river system. They take advantage of the fact that the service times are negligible compared to the transit times and the geographical structure of the port locations in the river, and develop a highly effective polynomial algorithm to solve the problem.

Fagerholt and Lindstad (2000) study the real problem of determining an optimal fleet and corresponding fleet schedule for an offshore supply vessel operation. They use a mixed integer programming formulation combined with the a priori generation of alternative vessel routes to solve the problem optimally. Based on the study, a new fleet and schedule were used, and more than 7 million dollars were saved in comparison with the previous operation mode. Another case study in the design of a transport system is described in Larson (1988). There, the problem of designing a new system to transport municipal sewage sludge from city-operated wastewater treatment plants to new ocean dumping sites 106 miles offshore is studied. An optimisation model is developed, providing an integrated framework for considering the design of an optimal fleet size and mix and the local storage capacities.

Murotsu and Taguchi (1976) study the problem of determining both the vessel fleet size and composition. As in our problem, the vessel fleet is to operate only between one port loading and one port discharging. For optimally solving the problem, they apply dynamic programming and (other) non-linear programming techniques. The effects of the transport demand, draught limits, tolls, storage costs, etc., are discussed concerning the resulting optimum fleet size.

In contrast to the study described in this paper, the above references all use an optimisation approach. They also focus on the fleet design rather than on the design of the whole transport system or chain, except for Larson (1988). It is evident that there are many situations that cannot be represented mathematically because of the stochastic nature of the problem, the complexity of the problem formulation, or the interactions needed to adequately describe the problem under study. In our problem, the complexity is more on the interaction between the different parts along the transport chain, rather than on the fleet design. This is partly because the possible number of fleet configurations is rather restricted. According to Naylor (1966, 1971), simulation analysis is typically appropriate for modelling such interaction and to anticipate bottlenecks in a system.

The purpose of this paper is to show how a relative simple simulation analysis has been used to support the decision-making process of a real problem in designing a sea-borne transport system. Section 2 gives a detailed description of the sea-borne transport system to be designed, while Section 3 presents the simulation study. Conclusions are given in Section 4.

2. PROBLEM DESCRIPTION

This paper describes a real problem faced by a major international shipping company regarding the design of a sea-borne system for fresh water transport between Turkey and Israel. The problem originates from an agreement between Israel and Jordan, where Israel was committed to supply Jordan with a given yearly amount of fresh water. Since also Israel is short of fresh water, this water had to be transported from somewhere else. The shipping company experienced at the same time that their single-hull crude oil tankers could not be used in this trade any longer. This was a result of the introduction of international rules restricting the use of such single-hull vessels in this trade due the risk of oil emissions. Therefore, the shipping company had to find alternative use for these vessels and they wanted to study the possibilities for fresh water transport between Turkey and Israel.

The fresh water should be transported with high regularity at sea from Turkey to discharging buoy(s) by the coast in Israel, then in pipeline(s) from the buoy(s) to a tank terminal ashore and finally with pipeline from Israel to Jordan. The transport system is illustrated in Figure 1.

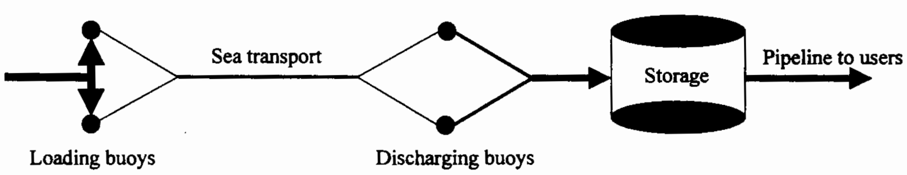

Figure 1: Illustration of transport system

The shipping company wanted to perform a study regarding the design of the system satisfying the regularity requirements. The study should aim at answering questions like:

- What is the optimal number of vessels to use in the transport system?
- Should one or two discharging buoys be used?
- If two discharging buoys were used, could a common pipeline to the tank terminal be used?
- What is the necessary capacity of the tank terminal to maintain a continuous flow in the pipeline between Israel and Jordan?

In order to answer the above questions, one had to study how the different parts along the transport chain interact and to reveal where bottlenecks arise. Another important part of the study was to examine how both planned and unplanned maintenance stops of the vessels, the discharging buoys and even the pipeline between Israel and Jordan affect the throughput of the whole system.

3 SIMULATION STUDY

A simulation approach was chosen to study the problem. To develop a simulation model, we used Powersim (Powersim, 1994). Powersim is a Windows-based software package that allows for the formulation of models in a graphical notation, which makes it easy and intuitive to build models (see for example Figure 2).

Section 3.1 presents the main features of the simulation model that has been developed while Section 3.2 gives a brief description of the user-specified input needed for the model. Section 3.3 shows some examples of the output from the simulations and how these results are presented in the simulation tool.

3.1 Simulation model

The model developed represents two main flows: The flow of the ships and the flow of water. Each ship was modelled as a flow from one condition to another through the ships' roundtrip, i.e. from waiting condition to mooring, to loading, to unmooring etc. At any point in time there might be a breakdown of the ship, the loading system etc. according to given input. Both regular maintenance and planned stops, like dockings, were incorporated in the model. No random or other distributed failures were allowed in the model, though it could easily be incorporated.

The loading situation was given and fixed, as two buoys with "nearly unlimited" capacities already existed. Based on experience, maintenance and revision stops were given as input to the model with the usual given interval or as single stops at specified times.

The unloading harbour was not built and it was therefore interesting to evaluate both one and two unloading buoys, with one common or two separate pipelines to a storage tank ashore. The unloading capacity was dependent both on the characteristics of the buoy(s) and the ships' unloading capacity.

From the storage tank a pipeline to Jordan needed to be built. The pipeline including pumping and booster stations along the line were given by a flow capacity. One essential requirement was that flow had to be kept at constant rate and flow failures had to be avoided.

Except for the transport with the ships which represents a batch or discrete flow, the flow of water was assumed to flow continuously depending on the most restricting bottleneck(s) along the chain. It was assumed that the pipeline was filled with water at the outset of simulation. However, if the tank storage became empty and no ships were discharging, no water was delivered at the pipeline end immediately and a flow failure occurred.

An Excel worksheet was used as input/output application. The simulation time step chosen was one hour. By running a given simulation, it was easy to monitor the simulated situation as time goes along. Figure 2 shows how the fresh water flow from discharging in Israel to Jordan is modelled. The figure gives a picture of the simulated state at a given time instance.

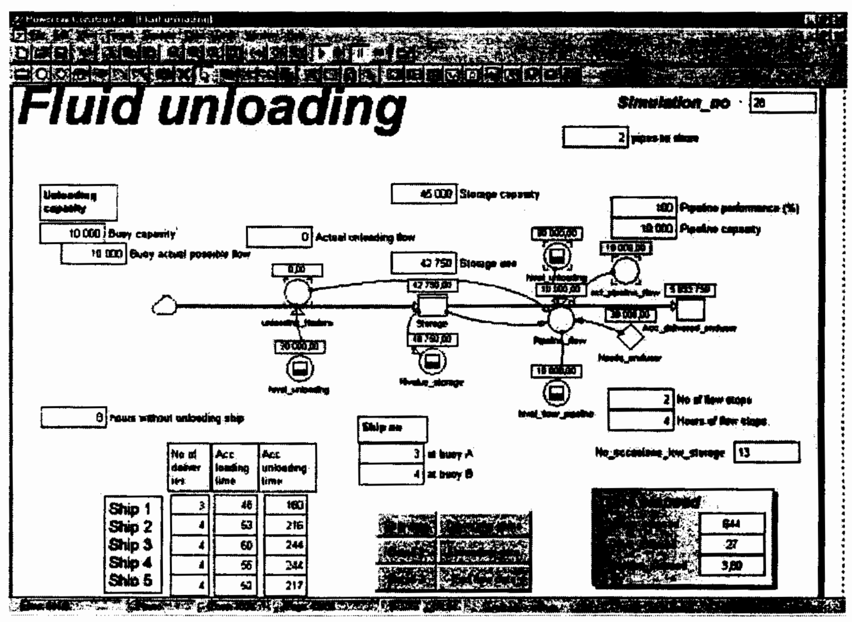

Figure 2: Modelling the fresh water flow from discharging in Israel to end-users in Jordan

3.2 Simulation input

The user has the possibility of specifying and changing a number of input parameters in order to test the various options. This actually corresponds to testing alternative transport systems. The most important options to be specified are listed below.

Simulation results

	Simulation no.	22	23	27
	Simulation length (hours)	176	8760	6126
	- in weeks	1	52.1	36.5
Input parameters	Number of ships	4	4	4
	Number of loading buoys	2	2	2
	Number of discharging buoys	2	2	1
	Number of pipes to shore	2	2	1
	Time for mooring loading (hours)	4	4	4
	- for unmooring (hours)	2	2	2
	Time for mooring discharging (hours)	4	4	4
	- for unmooring (hours)	2	2	2
	Availability loading buoys	99	99	99
	Availability discharging buoys	95	95	95
	Availability end pipeline	99	99	99
	Availability ship 1	95	95	95
	Availability ship 2	96	96	96
	Availability ship 3	99	99	99
	Availability ship 4	94	94	94
	Availability ship 5	99	99	99
	Maximum storage set (m3)	48 750	52 750	50 000
	End pipeline capacity (m3/h)	10 000	10 000	30 000
Central output parameters	Total shipped (m3)	1 302 000	79 785 000	50 153 000
	Total delivery at end (m3)	1 292 000	79 785 000	50 153 000
	Ship waiting - total hours	129	842	6 777
	- for loading	41	73	47
	- for discharging	88	769	6 730
	Maximum storage use (m3)	48 750	52 750	45 500
	Number of pipeline stops	1	79	161
	Hours of end pipeline stops	1	695	1 417
	Ship 1			
	- total loading time (hours)	12	804	528
	- total discharging time (hours)	30	3 024	1 290
	Ship 2			
	- total loading time (hours)	24	840	528
	- total discharging time (hours)	62	3 372	1 340
	Ship 3			
	- total loading time (hours)	24	828	516
	- total discharging time (hours)	66	3 289	1 361
	Ship 4			
	- total loading time (hours)	22	759	473
	- total discharging time (hours)	64	3 293	1 225
	Ship 5			
	- total loading time (hours)	0	0	0
	- total discharging time (hours)	0	0	0
Acc. loading	Mooring time (hours)	27	1 099	695
	Loading time (hours)	81	3 230	2 044
	Unmooring time (hours)	14	550	348
	Transport time with cargo (hours)	127	6 311	3 987
	Failure time with cargo (hours)	4	304	139
Acc. discharging	Mooring time (hours)	20	1 093	3 987
	Waiting time for buoy (hours)	0	0	0
	Discharging time (hours)	222	12 978	5 216
	Unmooring time (hours)	8	544	342
	Acc. unavailability of fleet (hours)	24	1 430	691

Figure 3: Aggregated simulation results

For the vessels, the most important parameters to be specified are:

- Which type of vessels to use
- Sailing speed with cargo and in ballast for each vessel
- Cargo capacity for each vessel
- Unloading capacity for each vessel (tonnes/hour)
- The availability of the vessels

For the buoys (both loading and discharging), the user has to specify the following parameters:

- The number of buoys to use
- The loading/discharging capacity (tonnes/hour)
- The time needed for the vessels for mooring/unmooring
- The availability of the buoys

In addition, one has to specify the number of landing pipelines between the discharging buoys in Israel and the tank terminal, the flow capacity of the pipelines and the capacity of the tank terminal. The user can also specify the simulation length.

3.3 Simulation output

By specifying values for the parameters presented in the previous section, the simulation can be run. By running simulations with different values of the various input parameters, a number of scenarios were studied. The scenarios were entered in a way where the results from previous simulations very much guided the new parameter values to be entered. Since the practical number of scenarios was rather limited for this problem, we could evaluate all relevant solution alternatives.

The most important and aggregated output is given in Excel. Figure 3 gives an example of this output for three simulation scenarios. Simulation results are shown like the total waiting hours for the vessels, maximum storage use, number of end pipeline flow stops and of course the total amount of delivered water.

It is also possible to view some graphs which show the evolution in time of different parameters. Figure 4 shows details about the 'flow' of the ships as a function of time. It is possible to see where a given ship is at any time, for instance if it is waiting for loading, mooring for loading, sailing with cargo etc.. Other graphs show end delivery of water, storage usage and ship availability.

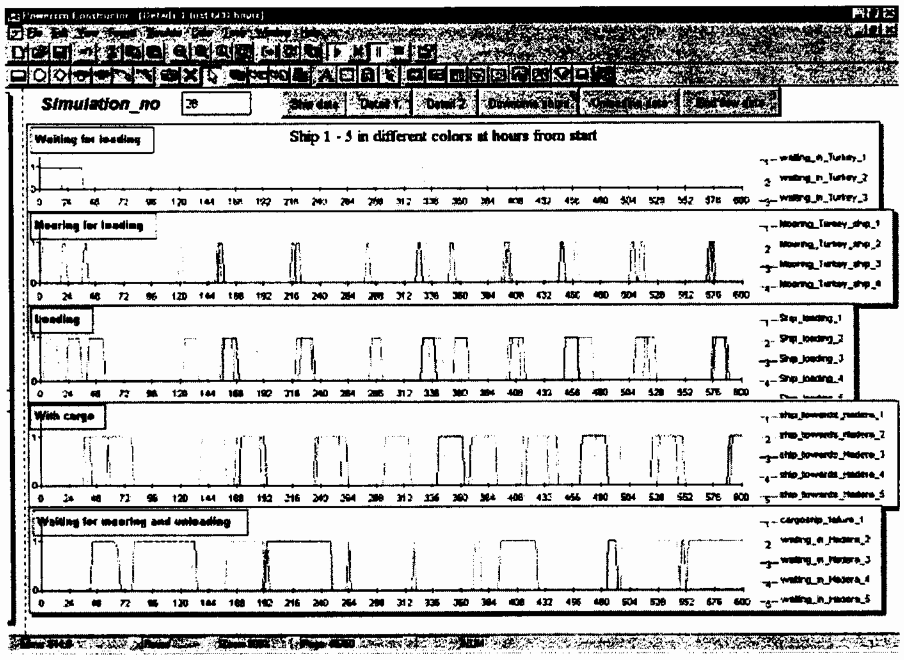

Figure 4: Detailed output regarding waiting of ships as a function of time

4 CONCLUSIONS

This paper presents a simulation analysis on the design of a sea-borne system for fresh water transport from Turkey to Jordan in the Middle East. The fresh water was to be transported with high regularity and robustness at sea from Turkey to discharging buoy(s) by the coast in Israel, then in pipeline(s) from the buoy(s) to a tank terminal ashore and finally with pipeline from Israel to Jordan.

The analysis was motivated by a real problem faced by a major international shipping company. The company wanted to examine the system design, particularly regarding the regularity requirements. The simulation analysis aimed at answering questions on the transport chain, such as the needed number, capacity and speed of vessels, capacity and number of discharging buoys, design and capacity of pipelines and necessary capacity of the tank terminal. Another crucial question was how sensible the chain was to failures of each component in the chain like the ships or loading/unloading buoys.

To answer such questions, a simulation model was developed and simulations were run for a number of scenarios. Based on this analysis, the shipping company was able to reveal where bottlenecks arose when the capacities of the different parts in the transport chain were changed. Hence, the simulation analysis was used as a decision support in designing an optimal transport system. The simulations revealed a lot of bottlenecks that were not obvious. For instance, the analysis showed that the capacity of the pipeline between Israel and Jordan had to be increased to ensure the required flow. It also gave a thorough understanding of the interaction between the different parts along the chain.

ACKNOWLEDGEMENT

The authors are grateful for the editing suggestions given by the editor and the referee(s). We also acknowledge the shipping company that gave us the opportunity to publish this work.

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