SIMULATION ANALYSIS OF INTERNATIONAL COAL TRANSPORTATION

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Abstract: *This study describes international coal transportation from a coal mining site in the South Gobi, Mongolia to Japan, which is located approximately 8,000 km to the west. The logistics of transportation from the origin to the final destination comprises of four stages: transportation by truck, Mongolian railway, Russian railway, and coal vessel. Specifically, performance measures such as the total transportation time and inventory levels at transshipment between two consecutive means of transportation are examined. A procedure to improve the efficiency of performance measures is proposed.*

Key words: *Simulation, Coal, International transportation, Inventory*

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1. Introduction

Mongolia is a landlocked country in the interior of the Eurasian continent, and Japan is an island country. Hence, passage through either Russia or China is inevitable during transportation of coal from Mongolia to Japan. In the former case, the Nahodka port of Russia is the port of shipment to Japan. In the latter case, the Tianjin port of China is the port used. In this study, simulation analysis is performed for international coal transportation from Ukhaa-Khudag, Mongolia to Japan via Nahodka, Russia.

The logistics of transportation from the origin to the final destination comprise from four stages. The colliery is Ukhaa-Khudag of the South Gobi province in Mongolia. In the first stage, the coal is transported 430 km by truck from Ukhaa-Khudag to Choir because a railroad has not been constructed between these two points. In Choir, the coal is unloaded at the temporary storage point to transship to the train. In the second stage, the coal is transported 951 km by rail to Sukhbaatar railport in northern Mongolia. In Sukhbaatar, the coal is unloaded at the temporary storage point to transship to the Siberian Railroad because the two railroad lines are operated independently by Mongolia and Russia. In the third stage, the coal is transported 4,980 km by the Siberian Railroad to Nahodka in Russia. After arriving at Nahodka station, the coal is unloaded for transport by ship. In the fourth stage, the coal is transported 1, 564 km to Japan by a bulk coal carrier. The distance between Mongolia and Japan is approximately 8,000 km.

The distance of the international coal transportation is relatively long, and four transportation means are involved. Hence, a bottleneck occurs if inefficient transportation exists somewhere on the way to the destination. Simulation analysis is performed to identify any bottlenecks and to find a more efficient transportation method by varying the conditions of the transportation means. The procedure used to seek better performance measures for the international transportation and the summary of the resulting simulation experiments are described.

2. Literature Review

There are two mining methods: open pit (i.e., surface) mining and underground mining. Surface mining, which can be used when the ore is close to the Earth's surface, is an older and more productive method than underground mining. Simulation models of the operations and materials handling system for an underground coal mine, used to identify the bottleneck of a conveyance system and determine more efficient mining and conveyance methods, were proposed (Miwa &Takakuwa, 2011). Procedures to determine the optimal number of trucks and to estimate the maximum mining capacity at an open copper pit was proposed (Tan et al., 2012). In addition, the use of operation process simulation for Six Sigma projects to illustrate the processes of defining, measuring, analyzing and improving the current process was introduced (Chinbat&Takakuwa, 2008).

Simulation modelling and the analysis of coal transportation systems have been studied. The simulation of a complex coal conveyance system was described, and the effects of various coal supply patterns and plant operating policies were compared (Walkley & Hutson, 1969). The strategic problem of moving coal from mines in the west of Canada to a power station far away in the east was investigated (Ash & Waters, 1991).

A railroad infrastructure simulator in which a reusable simulation tool specially designed to evaluate the impact of infrastructure changes on rail lines or load/unload terminals was presented (Fioroni et al., 2005). A flexible module-based modelling for large-scale truck transportation inventory systems was proposed (Miwa & Takakuwa, 2005). The concept of using computational intelligence methods in conjunction with discrete event simulation models of chosen logistics processes was presented (Karkula & Bukowski, 2012).

3. International Coal Transportation

Fig. 1 shows a convenient illustration of the logistics of coal transportation from Ukhaa-Khudag, Mongolia to Japan. The logistics of transportation from the origin to the final destination comprise four stages. The colliery is Ukhaa-Khudag in the South Gobi province of Mongolia. In the first stage, the coal is transported 430 km by truck from Ukhaa-Khudag to Choir. Then, in Choir, the coal is unloaded at the temporary storage point to tranship to the train. In the second stage, the coal is transported 649 km by rail to Sukhbaatar. In Sukhbaatar, the coal is unloaded at the temporary storage point to tranship to the Siberian Railroad. In the third stage, the coal is transported 4,980 km by the Siberian Railroad to Nahodka in Russia. After arriving at Nahodka station, the coal is unloaded to transport by ship. In the final stage, the coal is transport 1,564 km by a bulk coal carrier to Japan. Coal is also transported overseas by ship to locations such as India. Once again, the coal is transported by truck, twice by rail in Mongolia and Russia and by ship. Three storage points are located between pairs of consecutive transportation means. In this study, only coal transportation from Mongolia to Japan is analyzed.

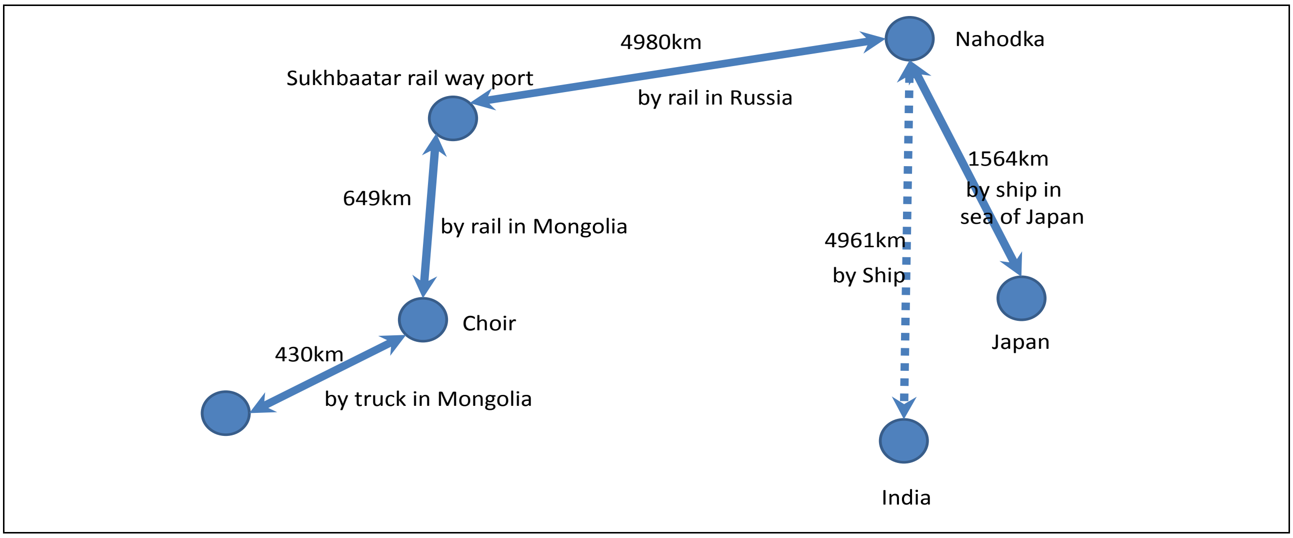

Fig. 1. Coal transportation from Mongolia to Japan

The list of parameters and the associated issues for international coal transportation is summarized in Tab. 1.

by truck	From Ukhaa-Khudag	To Choir
Distance	430 (km)	
Truck size	100 (ton)	
Verocity	6 (km/hour)	
Demand (Number of Truck)	Tria(2,2.4,3)	
Unloading Time (from Trucks)	RTIA(3,15,30) (min.)1	Choir
by rail	From Choir	To Sukhbaatar
Distance	649 (km)	
Train size	48 (trains)	68 (ton/train)
Verocity	40 (km/hour)	
Unloading Time (from tonnage trains)	TRIA(0.5,1,1.5) (day)	Sankhbaatar
by rail	From Sukhbaatar	To Nahodka
Distance	4980 (km)	
Train size	70 (trains)	68 (ton/train)
Verocity	20 (km/hour)	
Unloading Time (from tonnage trains)	TRIA(0.5,1,1.5) (day)	Nahodka
by Ship	From Nahodka	To Japan
Distance	1564 (km)	
Ship size	19040 (ton)	
Verocity	20 (km/hour)	
Unload Time (from Ship)	TRIA(1,2,3) (day)	Japan
by Ship	From Nahodka	To India
Distance	4961 (km)	
Ship size	14280 (ton)	
Verocity	15 (km/hour)	
Unloading Time (from Ship)	TRIA(1,2,3) (day)	India

Note: 1) TRIA: triangular distribution

Tab. 1. The list of parameters and the associated issues related to international coal transportation

4. Simulation Analysis

4.1 As-Is Model

In this study, the simulation model was developed with Arena (Kelton et al., 2010). An associated animation is shown in Fig. 2.

Simulation experiments were performed with a warm-up period of 60 days, a replication length of 365 days, and 10 replications, using the parameters indicated in Tab.1.The simulation results for the transport time and waiting time, under the condition that the average daily production volume is between 200 and 300 tons, are summarized in Tab. 2.

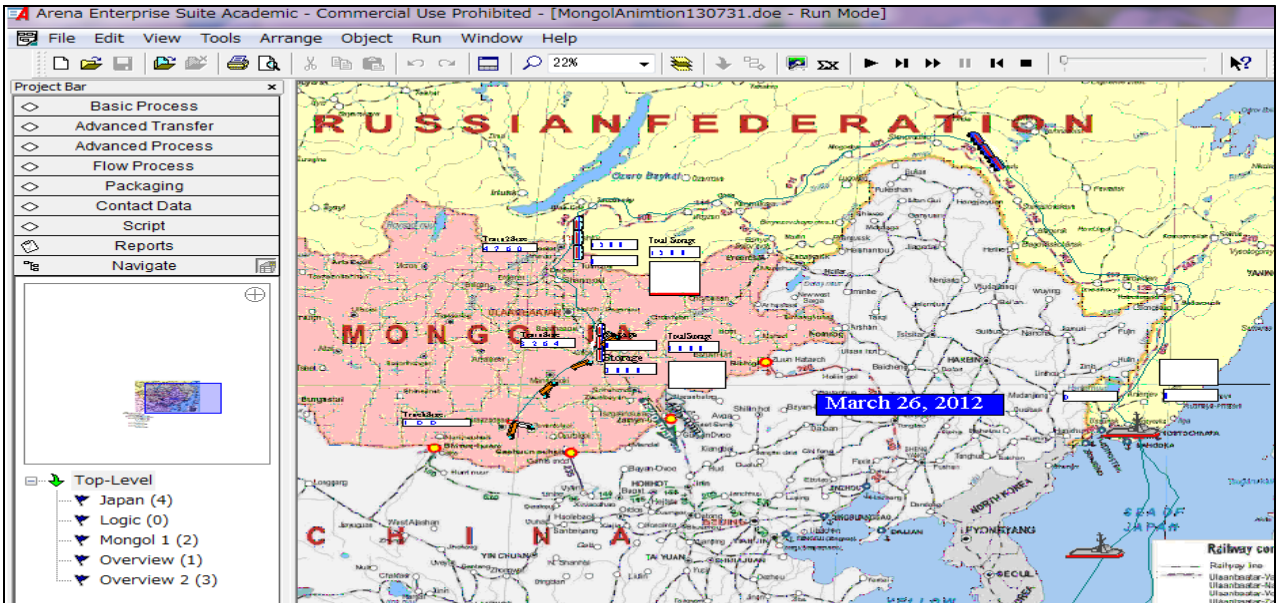

Fig. 2. Animation of the model

Transport time (days)	17.30
Waiting time in Mongolia (days)	5.00
Waiting time in Russia (days)	52.05
Waiting time to Japan (days)	81.00
Total time (days)	155.35

Tab. 2. Transport time and waiting time

As determined by performing the simulation experiments, the average transportation time is 17.3 days, the average waiting time is 138.5 days and the average total time is 155.35 days. Fig. 3 shows the breakdown of the total time. This figure shows that 89 percent of the total time is waiting time; the waiting time to Japan in Nahodka is 50 percent of the total time, the waiting time in Sukhbaatar is 36 percent of the total time, and the waiting time in Choir is 3 percent of the total time.

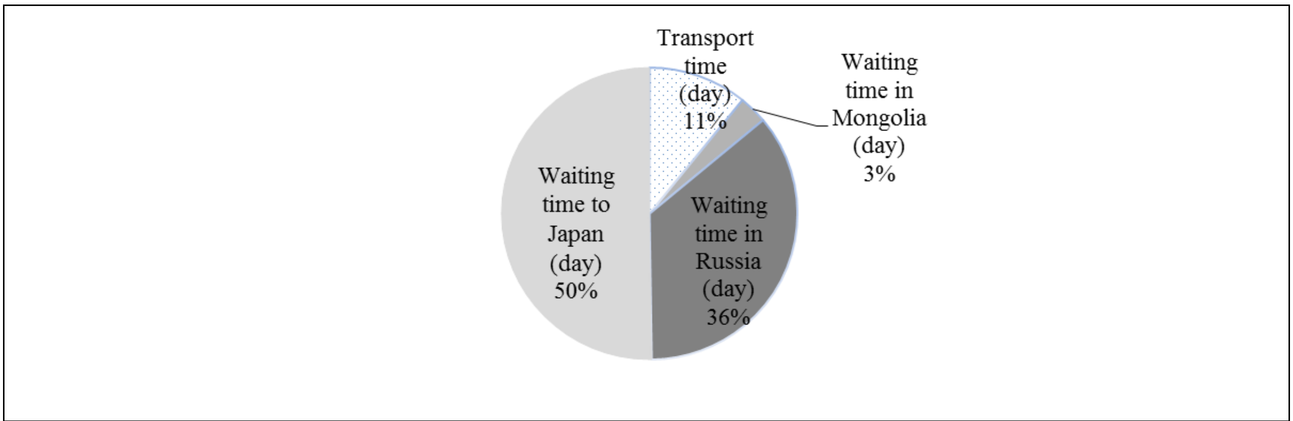

Fig. 3. Pie chart of the transport time and the waiting time

Next, a series of simulation experiments was performed under the condition that daily demand would increase to three times with an increment of 0.1, with the baseline condition of 200 to 300 tons per day at the coal mining site set to 1.0. The 95 % confidence interval for the average numbers of round trips per year are shown in Fig. 4 as the amount of transportation by train and by ship between any two consecutive points in Mongolia, Russia, and Japan. As shown in this figure, the number of round trips between two stations in Mongolia increases as the daily demand increases, whereas the numbers of round trips using the other forms of transportation is almost the same as the baseline condition, no matter how much the daily demand increases.

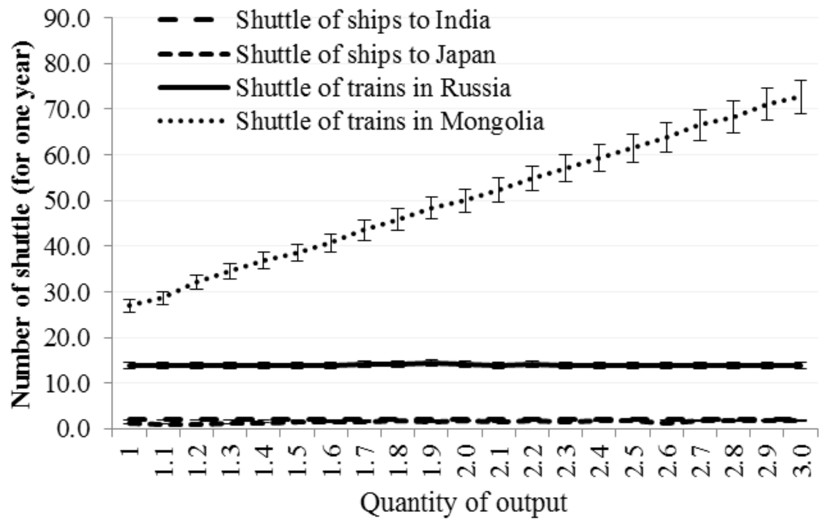

Fig. 4. Number of round trips in one year

The 95 % confidence intervals for the inventory at Choir in transshipment from trucks to train and the inventory in Sukhbaatar in railroad transshipment are shown in Fig. 5. Because the amount of coal transportation increases in Mongolia, the average inventory level increases in proportion to those of coal transportation.

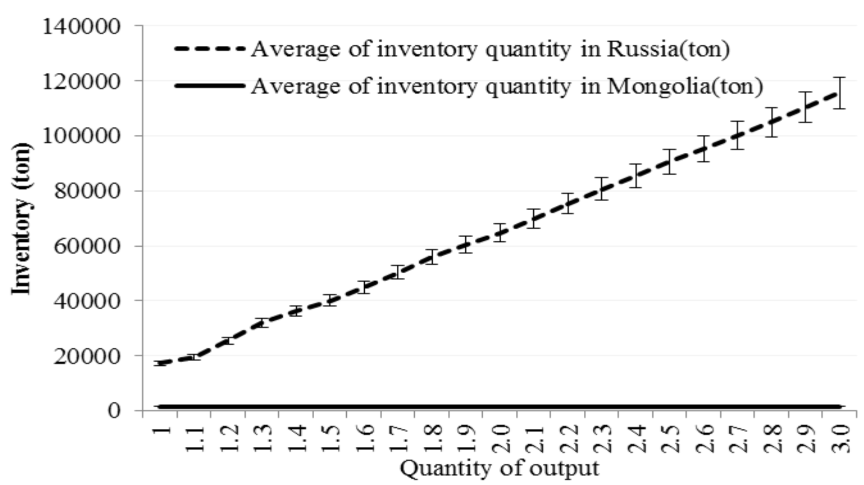

Fig. 5. Average inventory

Fig. 6 shows the 95 % confidence interval on the waiting time in Sukhbaatar in the railroad transshipment. The average waiting time increases from 57days to 152 days as the inventory increases. In addition, the waiting time at Nahodka, Russia remains approximately 84 days. However, the waiting time at Choir in Mongolia decreases from 5 days to 2 days.

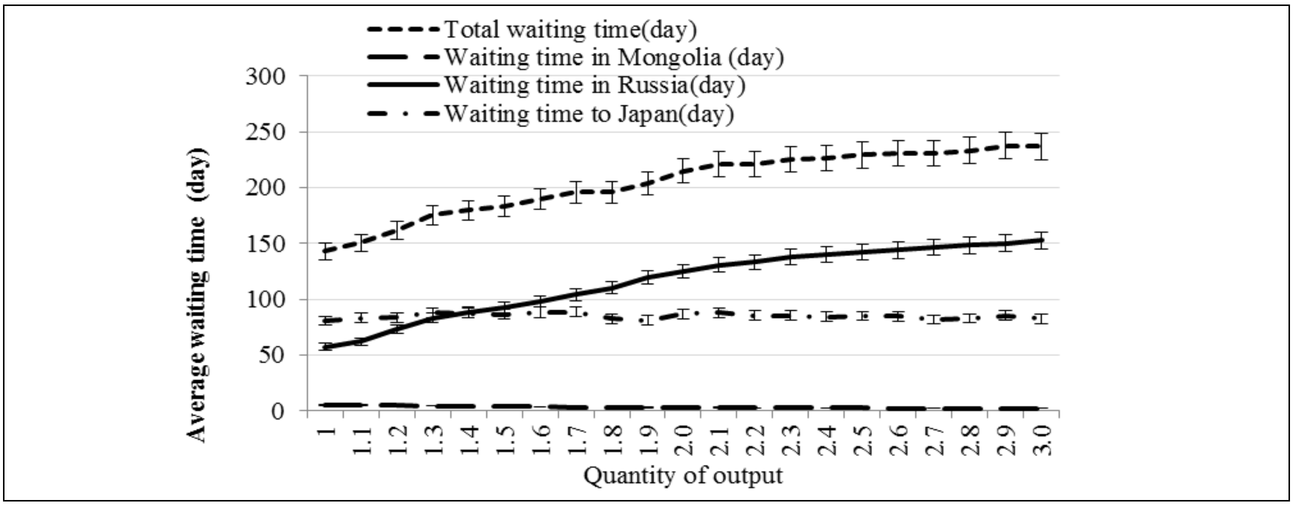

Fig. 6. Average waiting time

4.2 To-Be Models

Next, a series of simulation analyses was performed by defining several scenarios in which the major objective was to reduce the waiting time and then reduce the throughput time (that is, the total time spent on transportation). Hence, the number of train carriages was increased to carry more frequently, and the coal carriers were made smaller so that they could be fully loaded rapidly. The series of scenarios was as follows:

Scenario 1: one set of train cars on the Trans-Siberian Railroad
(68 tons × 70 cars = 4,760 tons)
capacity of coal carrier: 19,040 tons
Scenario 2: two sets of train cars on the Trans-Siberian Railroad
(2 × 68 tons × 70 cars = 9,520 tons)
capacity of coal carrier: 19,040 tons
Scenario 3: two sets of train cars on the Trans-Siberian Railroad
(2 × 68 tons × 70 cars = 9,520 tons)
capacity of coal carrier: 10,000 tons
Scenario 4: three sets of train cars on the Trans-Siberian Railroad
(3 × 68 tons × 70 cars =14,280 tons)
capacity of coal carrier: 10,000 tons

Simulation experiments were executed under the conditions of each scenario. As in the previous simulation experiments, this series of simulation experiments was performed under the condition that the daily demand would increase to three times with an increment of 0.1, with the baseline condition of 200 to 300 tons per day at the coal mining site set to 1.0. The resultant throughput time in each scenario is summarized in Fig. 7. The waiting time in Sukhbaatar in railroad transshipment is summarized in Fig. 8. The waiting time in Nahodka, Russia is summarized in Fig. 9. The inventory in Sukhbaatar in railroad transshipment is shown in Fig. 10. The 95 % confidence intervals for the corresponding averages are shown in Figs. 7 through 10.

As shown in Fig. 7, the throughput time occasionally decreases due to the timing of full loading, but it generally increases as the production volume increases at the coal mining site in scenario 1. In scenarios 2 and 3, the throughput time decreases to 1.6 times the production volume. However, although two sets of train cars are installed on the Trans-Siberian Railroad, the waiting time in Sukhbaatar in railroad transshipment increases to more than 1.7 times the production volume. In scenarios 2 and 3, by introducing smaller capacity coal carriers, i.e., a 10,000-ton capacity, the waiting time at Nahodka decreases; therefore, the throughput time decreases. In scenario 4, because three sets of train cars are installed on the Trans-Siberian Railroad, the throughput time decreases to 2.4 times the production volume. The graphs in Fig.10, showing the inventory at the transshipment in Russia, look similar to those in Fig. 8 showing the average waiting time to Russia.

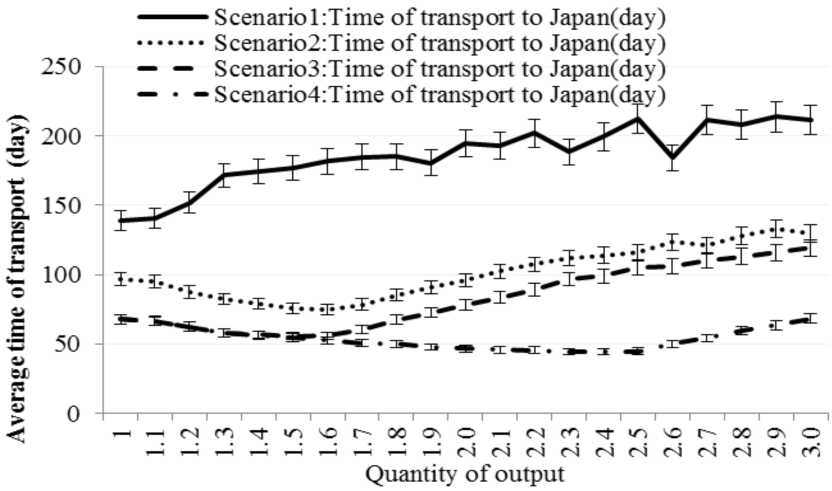

Fig. 7. Average transportation time

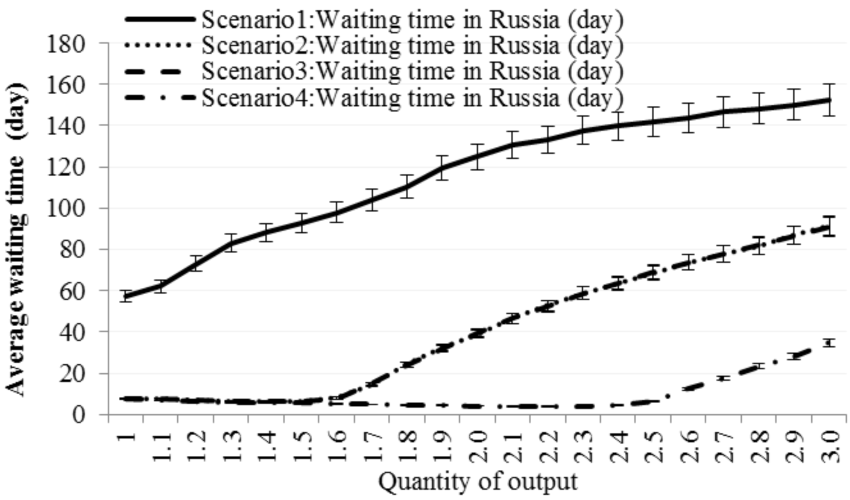

Fig. 8. Average waiting time in Russia

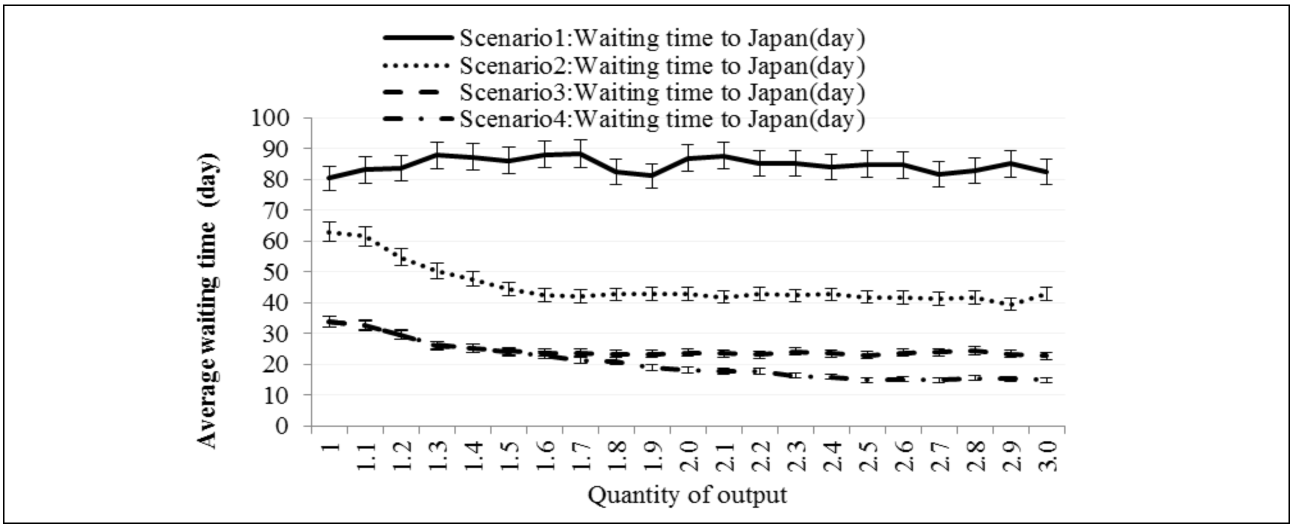

Fig. 9. Average waiting time to Japan

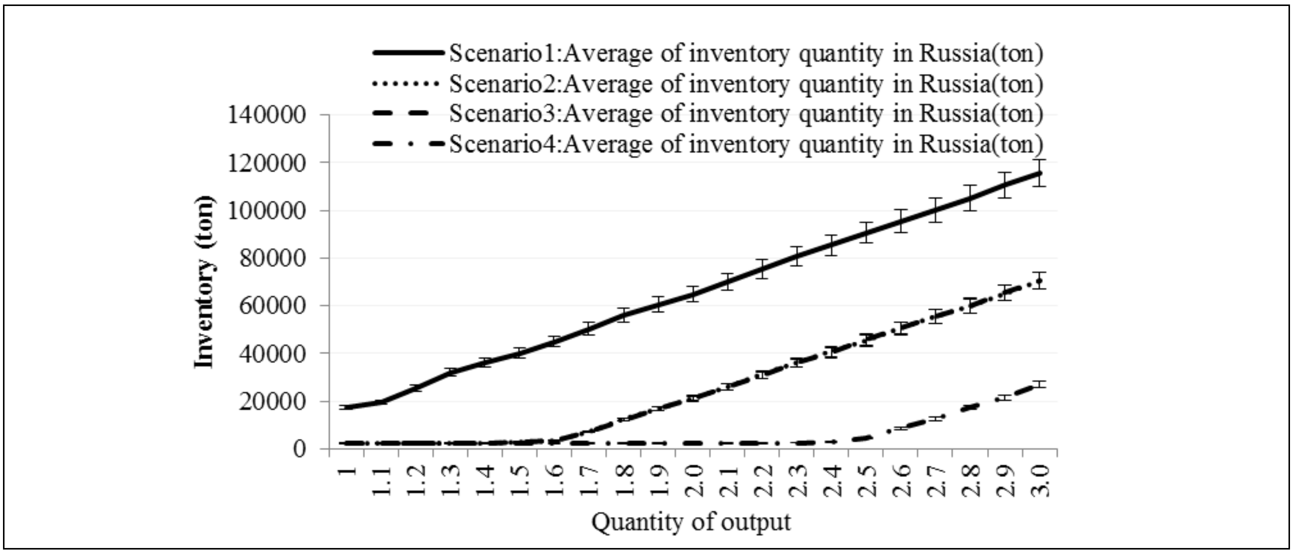

Fig. 10. Inventory at the transshipment in Russia

5. Conclusion

This study described the international coal transportation from coal mining site in the South Gobi, Mongolia to Japan. The logistics of transportation from the origin to the final destination comprise four stages: transportation by truck, Mongolian railway, Russian railway, and coal vessel. In addition, the logistics of operating in multiple countries are substantially more complex than within a single country. Performance measures such as total transportation time and inventory levels at transshipment between two consecutive means of transportation are particularly complex. A procedure to improve the efficiency of performance measures is proposed. A bottleneck in the coal transportation is identified by performing simulation analysis. In addition, the throughput time, as well as the waiting time, in transshipment could be reduced at certain amounts of coal production by enhancing the corresponding capacities for the set of train cars on the Trans-Siberian Railroad or by reducing the capacity of the coal carrier. Then, cost-effectiveness analysis would be performed on international coal transportation, based on simulation analysis.

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