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Viacheslav Matsiuk[a], Oksana Yurchenko[b]

a) Operation of Transportation Processes Department, Rail Transport Operation Faculty, State University for Infrastructure and Technologies, Ukraine
b) Operation of Railways Commercial Activities Department, Rail Transport Operation Faculty, State University for Infrastructure and Technologies, Ukraine

MATHEMATICAL MODEL FOR ASSESSING THE RELIABILITY OF CARGO DELIVERY ON THE CASPIAN-BLACK SEA ROUTE OF THE NEW SILK ROAD

Abstract

The article analyzes possible options of goods delivery routes from China to EU countries through Ukraine. The most preferred route is presented in the form of a technological scheme consisting of five elements. In order to assess the reliability of cargo delivery on the Caspian-Black Sea Route, a mathematical model is considered. Presented model takes into account such linear parameters as the time of the cargo operation at the points of departure and destination, the vehicle transporting time on the corresponding element of the route, the average time of overload in junction points of rail and sea transport.

Keywords: new Silk Road, Caspian-Black sea route, mathematical model, reliability of cargo delivery

Introduction

Ukraine, which is still considered a major transit country with the highest transit potential in Europe, has rapidly lost this status over the past few years. After all, the volume of transit traffic, which was carried out mainly in the directions of Ukrainian seaports and western border railway crossings, decreased by 30–35% annually (Figure 1).

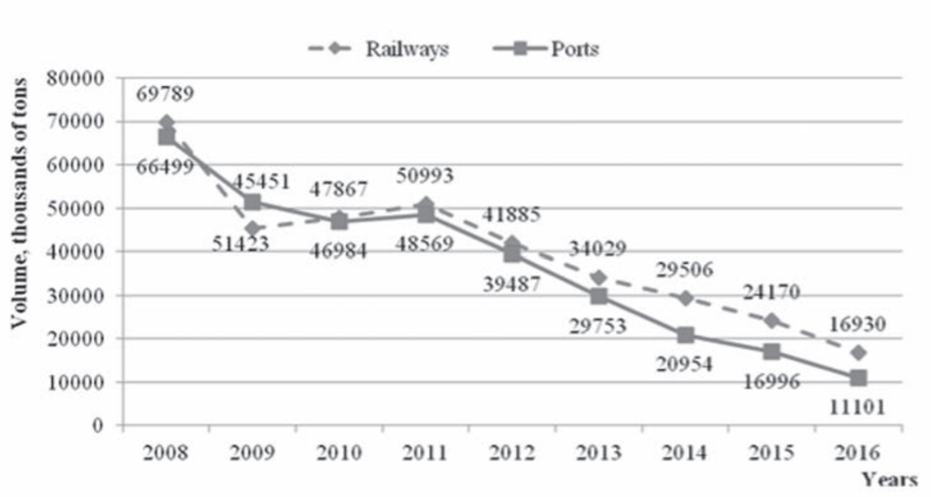

Figure 1. Dynamics of transit transportations volumes for 2008–2016 years
Source: (Cfts.ogr.ua, 2016)

Ukraine is taking active steps to join the development process of one of the three routes of the New Silk Road. The route from China, that geopolitically and in terms of economic potential is interesting for our country, runs through Central Asia, Iran, the Caucasian countries and the Ukraine (Miecznikowski, Radzikowski, 2017). Negotiations on participation in the project have been ongoing over the last few years (Me.gov.ua, 2017). The catalyst for joining the project was the Russian economic sanctions and blocking the transit of Ukrainian cargoes.

1. Analysis of previous researches on reliability

One of the effective means of optimizing transport systems and improving the quality of transport services is the modeling. The urgency of the transport flows modeling is evidential; therefore, a large number of scientific publications are devoted to the assessing of the transport flows mathematical models.

The reliability theory questions attached great value of scientists B. Gnedenko, V. Kovalenko, I. Ushakov. However, the emphasis in the main work was on technical reliability. At the same time, works by P. Gruntov, I. Sotnikov, F. Kochnev are devoted to research of reliability of technological systems. These studies were conducted more than 30 years ago in the absence of an integrated assessment. The influence of the human factor on the reliability of railway transport systems operation is detailed in the works of prof. V. Samsonkin (Matsiuk, 2017).

A significant number of scientists, both domestic and foreign, were engaged in the development of methods and models for the standardization and rationalization of technological processes of stations and lines sections. The results of their studies were to improve the technological processes, methods of rationing operations, processing, and the capacity. However, in other developed countries, scientists conducted a study of the railway transport technological processes in order to develop measures to perform the deadlines for the delivery of cargoes (Matsiuk, 2016).

2. Analysis of the New Silk Road routes through Ukraine

The main goals of the modern Silk Road for China are the logistical and economic security of the country, the development of the economic potential of the north-western regions of the China, the diversification of trade routes, the reduction of the goods delivery time, and the expansion of trade. Some of the participating countries among the most important strategic tasks see the development of alternative routes bypassing Russia. For example, for Georgia, as for Ukraine, such a route is a matter of national security.

Investors will look for safer places than sanctioned countries. Ukraine has to offer its investment attractive project.

China, as the main supplier and consumer of goods on the New Silk Road, sees its transport links with EU markets as "multi-alternative", as evidenced by its initiative, the One Belt – One Road Initiative. In the Figure 2, at least two routes from China approach the Caspian Sea and further lead through Azerbaijan, Georgia to the Black Sea, and then to Ukraine. In the future, the Trans-Siberian route will have a railroad branch to Azerbaijan, Georgia and further to the Black Sea and by the sea to Ukraine.

As the most promising route, consider the Caspian-Black Sea route. At the same time, China has already proposed the construction of a high-speed railway, in which passenger trains will run at speeds of 250–300 km/h, and cargo container trains at 120 km/h. The railway will pass west from the city of Urumqi in China through Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan to the capital of Iran (Tehran). In essence, it can become competitive for Ukraine by the Trans-Iranian route, which is given below (Figure 3). Maybe it will be the beginning of the Caspian-Black Sea route through Ukraine, if a branch will be provided in Iran along the western shore of the Caspian Sea, and joining the Azerbaijani railways. Then the route can pass through Georgia to the ports of Poti/Batumi, where there is a ferry connection with Ukraine. But this project, in our opinion, is not very realistic and will not cause enthusiasm either in Iran or even more so in Turkey, which then will not receive the expected volumes of transportation.

To start a more realistic project that will go through Ukraine and will be an alternative to a possible Trans-Iranian route (Figure 3), which can possibly pass to Turkey and through a tunnel under the Bosphorus – directly into the EU countries. It is necessary to start building a line of approximately 600 km, the same standards as Urumqi – Tehran, from Ashgabat to the port of Turkmenbashi, where there is a ferry connection through the Caspian Sea to Baku. Then, in the territory of Azerbaijan and Georgia, to the ports of Poti / Batumi, where is the ferry connection with Ukraine. This route is shown in Figure 4. Although it has two ferry crossings, which may be an obstacle to the passing of goods, but its railroad part is obviously much shorter than the Trans-Siberian route that crosses the Caspian Sea from the south and west.

Figure 2. Perspective directions of the Silk Road from China development
Source: (Khanna, 2016)

Figure 3. Possible Trans-Iranian route through Ukraine
Source: (own elaboration based on: SeaRates, 2018)

Figure 4. Possible Caspian-Black Sea route through Ukraine
Source: (own elaboration based on: SeaRates, 2018)

3. Establishment of a mathematical model

The process of delivering goods from China to the European Union within the appropriate route can be conditionally represented as the interaction of five technological elements (Figure 5). The first, third and fifth elements represent the railroads (land route element), the second and fourth – the sea lines (marine route element).

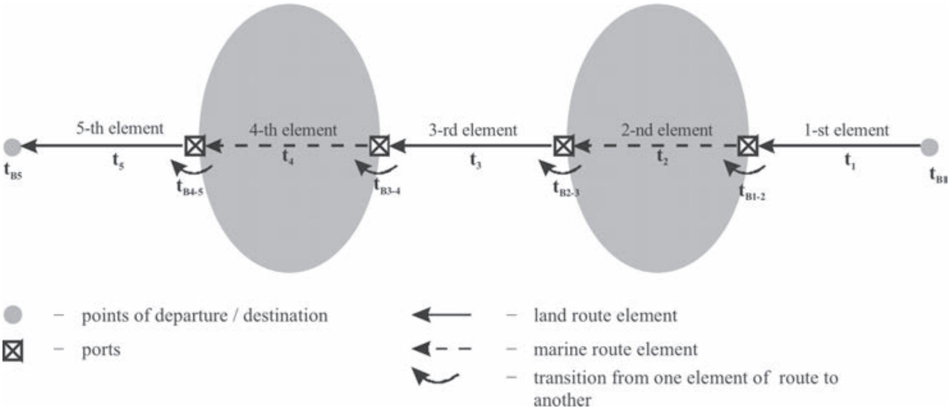

Figure 5. Possible Caspian-Black Sea route through Ukraine
Source: (own elaboration)

There are several options for arranging the delivery. Mostly, the difference between options will depend on the organization of maritime lines. The most attractive way is to organize maritime connections using ferry lines, in which railway wagons, together with cargo, are transported by sea as separate cargo modules. In this variant, railway cars (providing technical interoperability of the railways of all countries of the route) will rotate between the point of departure of the goods and the destination, that is, within the entire route of delivery.

Then, the total turnover time of rolling stock on the entire route will be:

$$Q_R = 2(t_{E.1} + t_1 + t_{E.1\text{–}2} + t_2 + t_{E.2\text{–}3} + t_3 + t_{E.3\text{–}4} + t_4 + t_{E.4\text{–}5} + t_5 + t_{E.5}),$$

where $t_{E.1}$, $t_{E.5}$ – average cargo time at departure and destination points, hours;
$t_1, \ldots t_5$ – average vehicle transit time on the route element, hours;
$t_{E.1\text{–}2}$, $t_{E.2\text{–}3}$, $t_{E.3\text{–}4}$, $t_{E.4\text{–}5}$ – the average time of overload at the points of junction of rail and sea transport, hours.

The average delivery time is approximately equal to the total turnover time of rolling stock, that is:

$$t_{delivery} = \frac{Q_R}{2},$$

or

$$t_{delivery} = t_{E.1} + t_1 + t_{E.1\text{–}2} + t_2 + t_{E.2\text{–}3} + t_3 + t_{E.3\text{–}4} + t_4 + t_{E.4\text{–}5} + t_5 + t_{E.5}$$

In general, the need for a rolling stock (the number of railway tracks) can be defined as:

$$M_{cars} = \frac{Q_R N_{trains}}{24},$$

where N_{trains} – average daily traffic intensity of trains on the route.

The time of goods processing at points of overload in the conditions of uneven flow of goods essentially depends on the number of rolling stock on each element of the route. It is difficult to determine this time analytically.

Delivery reliability is formalized as the probability that the total delivery time (i.e. the actual time t_{fact}) of the cargo to the destination point will exceed the established (normative time $t_{normative}$):

$$\xi = p(t_{fact} > t_{normative}),$$

Delivery reliability is practically possible to determine only experimentally or in fact during the reporting period as the proportion of delivery cases with an excess (Z_{exc}) to the total number of shipments on this route (ΣZ):

$$\xi = \frac{Z_{exc}}{\Sigma Z},$$

In order to evaluate the fail-stability of the system in the AnyLogic environment, an imitation model, consisting of a sequence of five queuing systems (QS), was developed (Figure 6).

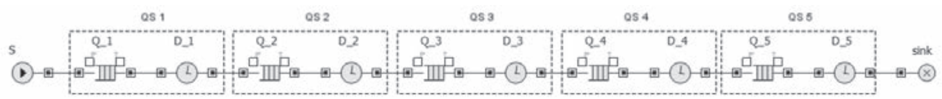

Figure 6. Simulation model
Source: (own elaboration)

The first, third and fifth QS – railways, the second and fourth QS are sea transport lines. During the experiments generated a forecast flow of about 10 billion tons of containers per year (one million TEU/year). The flow of applications and their processing are subject to the exponential distribution. Modeling time period is 20 years. The distribution of the total container delivery time is shown in Figure 7. With a reliability of $\xi = 0.95$, the delivery time for containers will not exceed 202 hours (or 8.4 days).

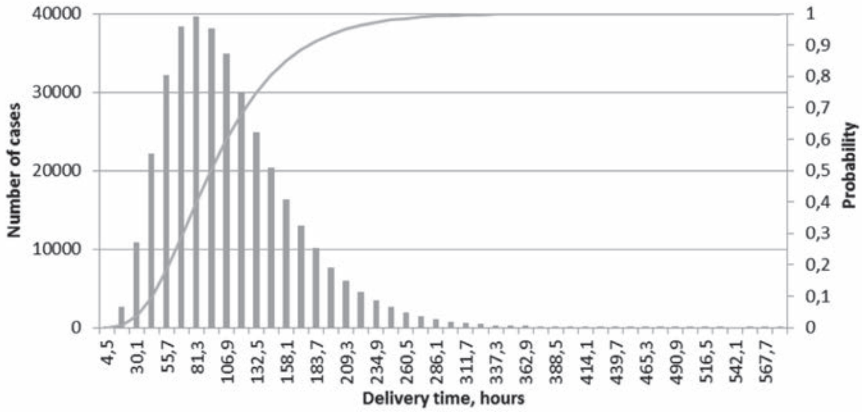

Figure 7. Distribution of total container delivery time
Source: (own elaboration)

To assess the stability of the system the dependency was researched of aggregate inter-operative downtime on the calculated intensity of containers. The results are presented in Figure 8.

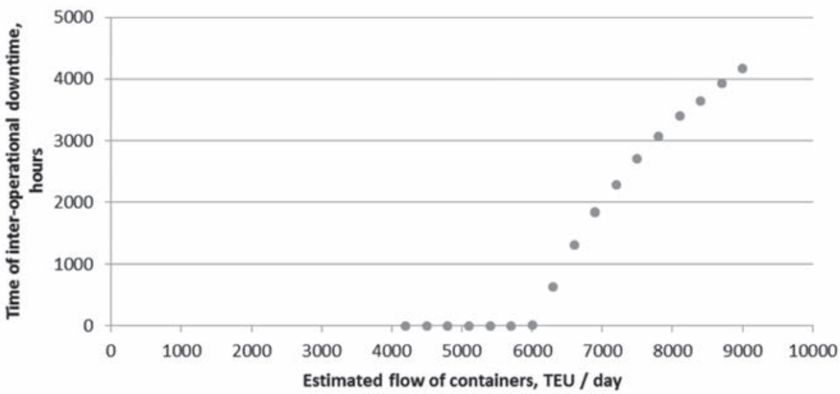

Figure 8. The dependence of aggregate interoperable downtime on the design intensity of the containers
Source: (own elaboration)

The results show, it a 6000 and more TEU / day flow there is a decrease of the technological stability of the transport system is observed.

Conclusions

The proposed mathematical model can be used for further researches. For example for simulation using programming language Java class library AnyLogic. The simulation definitely that the stability of the technological system on the Caspian-Black Sea route of the New Silk Road is provided at a calculated flow rate of up to 6,000 TEU per day.

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Corresponding authors

Viacheslav Matsiuk can be contacted at: vmatsiuk@ukr.net
Oksana Yurchenko can be contacted at: detut1@ukr.net