OPTIMISATION OF THE EXPORT STRUCTURE IN TRANSPORT COMPANIES: A CASE STUDY

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Abstract

With the increasing complexity of economic systems caused by the intensification of European integration processes and general globalisation trend, the problems of ensuring the optimal operation of transport companies are becoming especially important. Given these facts, the article’s purpose is to develop and test a structural modelling algorithm based on the system state indicator (entropy of the structure of the export freight system). Research methods used in the article include: statistical (structure and dynamics analysis), systematisation and comparison, system analysis methods (entropy characteristics), mathematical programming methods. The mathematical formulation of problems involves studying structural uncertainty due to the synergistic influence of interconnected structures. As a result of the optimisation calculations, the entropy index decreased as a consequence of the optimisation of the studied structures of export cargo. The study results using structural-dynamic modelling provide an opportunity to determine benchmarks for optimising the structure of export transportation. Therefore, they can act as indicators in the relevant field to substantiate the performance of large transport and logistics companies. The use of such approaches will help improve cooperation on a shared basis between Ukraine and the countries of Central Europe.

Implications for Central European audience: first of all, the algorithm of structural modelling containing stages is offered (structural-dynamic analysis; systematisation of the reasons that led to structural changes; mathematical formulation of the optimisation problem; numerical solution of the problem; interpretation of results and development of recommendations) as the theoretical contribution. Moreover, it has prospects for
implementation by European transport companies, as the strategic partners of Ukraine in the field of rail freight are the Central Europe countries. In turn, practical implications include: to test the proposed model, the process of forming the structure of export freight JSC "Ukrzaliznytsia" as a partner of big Central European export companies was chosen as the object of study.

**Keywords:** modeling; structure; system; entropy; export; freight transportation; optimization

**JEL Classification:** C50, L16, L92, C61

### Introduction

The country's global competitiveness in international markets is determined by its ability to ensure a certain level of development and the capacity to maintain this position. According to the Global Competitiveness Index (World Economic Forum, 2019), Ukraine has been ranked below 80th out of 140 possible for many years, in terms of infrastructure – below 50th. In terms of macroeconomic stability, Ukraine was ranked 131st in 2018 and dropped to 133rd in 2019 (out of 141 possible). Achieving and maintaining the desired level of macroeconomic indicators of the country can be achieved through the optimisation of export activities as a catalyst for the sustainable development of the transport industry (Kral et al., 2018). Sustainable development of the country in this context can be considered through the harmonious development of certain sectors of its economy, including infrastructure sectors. The infrastructure industries are able to improve the position in global rankings as an indicator of the level of sustainability of development.

Railway enterprises are one of the main branches of the Ukrainian economy as the most important component of the transport system. Railway transport of Ukraine has an operational length of railways which is more than 20,000 km, and it occupies a prominent place among railway companies in Europe. Ukraine's rail transport ranks fourth in the cargo transportation rating on the Eurasian continent. Only China and India are ahead by this indicator. Seven countries of the world are neighbours of Ukraine (Belarus, Poland, Hungary, Russia, Slovakia, Romania, Moldova), with which it is connected by rail transport corridors, including more than 50 border crossings. Of all modes of transport, the lion's share of cargo transportation belongs to railway transport, and it is almost 82%. Only 18 % of these transportations are realised by other modes of transport (road, water, air) (The main aspects of the Development Strategy of JSC "Ukrzaliznytsia" 2017-2021, 2021).

Given that railway transport belongs to the most important sectors of the Ukrainian economy, its sustainable development is of crucial importance. One should add that sustainable development requires green investments, which are more expensive than traditional investments (Moldovan, 2015). Research on the problems of sustainable development of railway transport, its main advantages over other modes of transport, as well as the main problems and challenges from the standpoint of the concept of sustainable development, are raised by Dvulit and Levchenko (2017). In this study, the authors draw on the proposed concept of sustainable development of railway transport enterprises as a system of interconnected components that balance the production and economic activities of such enterprises for the needs of the state's economy. This involves determining the
optimal export structure. At the same time, sustainable development is considered as a structural definition of the ratio of the whole (sustainable development of the country) and the part (sustainable development of the railway industry by type of activity, one of which is export cargo transportation by railway transport enterprises). Export as a type of foreign economic activity is a factor in ensuring such an important macroeconomic indicator of the country as Gross Domestic Product (GDP). Firstly, export is a factor in the formation of macroeconomic indicators. Secondly, it is a factor indicating the degree of involvement in the international division of labour. And thirdly, it has a synergistic effect on all sectors of the economy and, as a consequence, on ensuring the sustainable development of the country. As Meyer (2021) claims, many countries have successfully facilitated rapid growth via the export-led growth nexus, and diversification and specialisation are essential components of exports (Szczepaniak, 2018). Therefore export activities require support by the state (Richter, 2015). Furthermore, physical capital plays a critical role in the success of a country’s exports. The government uses the budget to invest in public infrastructure, for example, roads and transport infrastructure (Le, 2022). Exports are an integral part of the overall economic potential of any state and largely determine the pace of its economic development (Pancenko & Ivanova, 2018), and there is a positive correlation between the export of goods and gross regional product (Horská et al., 2019). Therefore, to optimise the management of export activities, the authors proposed to use expert methods to obtain initial data, which are further the basis for determining adequate directions (Richter, 2015). In turn, Petrová et al. (2021), as well as Ključnikov et al. (2022), study the impact of risks on export activities. They suggested choosing additional information and the results of a study of the relationship between risk assessment and exports as a risk management tool. And Li (2018) proposes a comprehensive approach to studying the dependence of export dynamics on the interaction of entrepreneurial resources with institutional dimensions.

This review shows how complex and multidimensional is the said problem. Given these facts, the article's purpose is to develop and test a structural modelling algorithm based on the system state indicator (entropy of the structure of the export freight system). The remainder of the paper is structured as follows. The next section presents a literature review devoted to the problem. This is followed by the presentation of the research methods applied by the study. In turn, the next section presents the research results and discussion. Finally, we conclude as well as present the limitations of our study.

1 Literature review

1.1 Theoretical background

The works of many scholars are devoted to studying the directions of optimisation of the structure of the transport system. Most of them analyse individual factors influencing the activities of transport companies. These include: technical, political, economic, social, regional, environmental, the degree of development of information and communication technologies, the quality of transport management, the ratio of export-import activities. (e.g. Shpak et al., 2018; Shpak et al., 2021a; Prokopenko et al., 2020a; Kolarov & Georgieva, 2020). For example, the main factors influencing the general organisation of the state of transport and logistics without taking into account the types of connections are investigated by Mindur and Hajdul (2013) and Prokopenko et al. (2020b). The main aspects raised by the authors include a set of social, economic and environmental factors. Trade facilitation
reforms are improving the export performance of these countries but per capita. The impact of physical infrastructure and information and communication technologies is becoming increasingly important depending on the welfare of the country (Portugal-Perez & Wilson, 2012; Androniceanu, 2021). However, the growing imbalance between imports and exports in world trade may lower transport companies’ productivity (Othman et al., 2020).

It should also be noted that many theorists, practitioners and analysts have investigated the problems of studying the factors that influence the country’s macroeconomic indicators. For example, Sharko et al. (2019) argue that the calculation of a priori and a posteriori information and the value of entropy provides an opportunity to regulate the process of accumulation of the required amount of information in management decisions. Furthermore, the need to investigate the interrelation between trade indicators and railway transport activities, which contributes to their sustainable development and acquiring synergistic effect, was raised by Sun et al. (2019). The authors substantiated the use of the entropy method for determining the level of railway transport and trade development.

One should add that a number of authors have also investigated the impact of transport infrastructure on the macroeconomic indicators of the state, evaluating and forecasting such impacts at macro, meso and micro levels: the main direction of their research was to forecast the volumes of cargo without studying their structure (e.g. Gurnak et al., 2019). In turn, the study of Zhou and Hu (2017) examines the stability of a complex economic system on the example of railways in different parts of China by different stages of the production cycle. Dobrodey et al. (2018) propose a model of the application system which allows analysing specific regional railway system development projects. It takes into account the strategic state priorities and goals and corporate objectives of sustainable development of railway companies. Shpak et al. (2021b) propose a model of multidimensional analysis of the structure of transport companies’ services and the degree of customer satisfaction). The connection between transport infrastructure and regional economic growth based on a multidimensional analysis of transport infrastructure is analysed by Hong et al. (2011). And the impact of transport infrastructure on economic growth in India using a vector error correction model to determine the relevant causal relationships was studied by Pradhan and Bagchi (2013).

In general, there are different approaches to identifying, grouping and evaluating the main factors influencing export activities. In particular, Fernandes and Winters (2021) studied the influence of political factors (Brexit referendum) as a quasi-natural experiment to study the impact of exchange rate shocks and uncertainty on the prices and volumes of export traffic for Portuguese exporters. One should mention that examining the problems of the impact of certain factors on exports, the researchers concluded that the combination of goods and services is closely linked to the level of export intensity (Aquilante & Vendrell-Herrero, 2021). Based on a study of six global management indicators as explanatory factors for exports and their components, Bah et al. (2021) have found that political stability, the rule of law, control of corruption, voice, and accountability have a positive effect on export performance. But of these, only voice and accountability have a positive effect on commodity exports. The study conducted by the authors was large-scale for 45 countries of Sub-Saharan Africa over almost 25 years.

Analysis of the literature on approaches to optimisation of the export activities has revealed that some authors analyse criteria for optimisation of the transportation process, whilst the
others study to indicators of exports or export structure. Modelling in the field of freight transport based on optimisation approaches for improving the process of transporting export cargo and taking into account the specifics of regional factors is presented by Zhao et al. (2015). Other authors, e.g. Wei and Dong (2019), studied the problems of organisational optimisation of domestic exports based on “dry ports” in the interior of China using network scenarios built by applying a two-criterion model of mixed-integer programming. Furthermore, Zhang et al., (2016) used approaches to integer optimisation of export rail transportation using binary variables as indicators of management decisions on the structure of goods. And finally, there are also authors who study the influence of transport factors using the conditional Bayesian delay propagation model (e.g. Zhang et al., 2019).

The analysis conducted allows to draw several conclusions: i) there is no doubt that the matter that is being analysed is complex and multidimensional; ii) the issue of optimisation structure of the export activities is a matter of analysis of a number of scholars; they analyse the said topic from different points of view, using different approaches; and iii) there is lack of the model that could serve as the effective structure for rail transport.

1.2 Structural and dynamic analysis of export freight transportation of Ukrainian railways

The railway industry is considered as one of the main factors in ensuring the stability of economic systems (Loo & Comtois, 2016). Ukrainian railway transport belongs to the most important ones in Europe. One predicts even that its importance will increase in the future. The last years were not so good for the Ukrainian railway companies (mostly to the pandemic of Covid-19). The total volume of transported goods in 2020 decreased compared to the previous year by 2.4% and amounted to 305.5 million tons, and the total turnover decreased by 3.4% and amounted to 175,587.2 million tkm. In 2020, 113.0 million tons of cargo were transported for export, which accounted for almost 37% of total freight traffic. The volume of these shipments decreased compared to 2019 by 2.8 million tons (-2.5%). As for the export turnover indicator, it showed similar trends. The share of cargo turnover for export in 2020 amounted to more than 44% of total cargo turnover. In 2020, it decreased compared to the previous year by 3017.00 million tkm (-3.7%).

It should be noted that over the 13 years under study, there have been significant changes in the structure of export cargo. Thus, the largest share (almost 30%) in the structure of exports in 2006 fell on ferrous metals, and iron and manganese ore was 17.8%. In 2018, the share of ferrous metals in exports fell to 15.23%, and the share of iron and manganese ore more than doubled to 34.76%. It is unlikely that such an export structure can be considered optimal because the share of raw materials in Ukrainian exports is growing significantly. This is evidence of inefficient management, as the opportunity to export value-added products instead of raw materials is lost.

In the structure of export traffic in the last years of the studied period, the first place is occupied by iron and manganese ore (from 18.84% in 2006 to 36.01% in 2015), the second – grain and grinding products (from 3.52% in 2007 to 26.89% in 2017), in third place – mineral materials (from 12.78% in 2016 to 23.95% in 2013), in fourth place – ferrous metals from 14, 8% in 2017 to 29.42% in 2006.
The main consumers of Ukrainian exports (according to transportation documents) are: Switzerland, China, Poland, Belarus, and Turkey. Due to the free trade zone with the European Union, exports of Ukrainian goods to these countries increased by 10%. Ukraine is currently in the top 10 largest exporters of agricultural products, in many positions in the top five. But Ukrainian exports are mostly raw materials. The share of high-tech exports is currently 5.5%.

About 59% of the ore mined in Ukraine is exported. A significant decrease in recent years has taken place in the direction of Ukrainian seaports, mainly to China, due to high competition among world suppliers. The main competitors of Ukrainian companies in the Chinese market are suppliers from Australia and Brazil.

In order to maintain its position, Ukrainian producers need to reduce production costs and offer raw materials with a higher percentage of iron content as the world market, including China, increases its focus on purchasing high-quality raw materials every year. In addition, due to inflated Ukrainian port fees compared to other ports, the logistical component of supplies of Ukrainian raw materials to Chinese ports is quite high, so domestic exporters are trying to replace China with more profitable markets by reorienting supplies to Western Europe. Thus, ore exports to Switzerland, Slovakia, Hungary, Austria, and others increased.

It should be noted that the increase in rail traffic was positively affected by the ban on the movement of vehicles weighing more than 40 tons by road. 80% of the processed grain in the ports of Ukraine is transported by rail. During the period of 2018, deliveries to Switzerland, which is the main destination country (according to transportation documents), increased.

The second place is occupied by the EU countries. The main volumes went to Germany, Latvia, and the Netherlands. According to The Ministry for Development of Economy, Trade and Agriculture of Ukraine (2020), Ukraine is among the TOP 10 largest suppliers of agricultural products to the EU (8th place). From 01.10.2017, exports from Ukraine to the European Union of most types of agricultural products take place without the application of customs duties. One should add that the Asian market, which is growing demographically, remains promising for Ukrainian farmers.

The third place in the structure of export traffic was taken by the Ministry of Construction Materials. Ferrous metals took the fourth place in the structure of export traffic. In 2017, exports of ferrous metals were the lowest in 20 years. The main reason for the decrease in the transportation of ferrous metals is the reduction of production due to the cessation of supplies across the line of contact within the Donetsk and Luhansk regions and the loss of metallurgical capacity of Alchevsk, Yenakiyevo, Makeyevka, and Donetsk plants. Despite the favourable situation in the world metal markets (high world steel prices, which are at their highest level since September 2014), Ukrainian metallurgy is in critical condition and has fallen to the level of twenty years ago. Metallurgical goods were exported to about 100 countries near and far abroad. The main shipments took place to Italy, Turkey, Russia, and the United States. Exports to Egypt fell significantly 2.5 times compared to last year and to Turkey 1.5 times.

The fifth place in the structure of export cargoes is occupied by non-ferrous ore and sulfur raw materials, and the sixth place by forest cargoes. The decrease was due to a ban from January 1, 2017 (for a period of 10 years) on the export outside the customs territory of
Ukraine in the mode of export of pine trees for the purpose of restoring the woodworking and furniture industries. Also, from November 1, 2015, the export of untreated timber of wood species was prohibited.

The conducted structural and dynamic analysis of export cargo transportation by types of cargo allowed to identify the main causes of structural changes in exports and group them: 1) temporary loss of Ukraine part of the regions for which the main branch of specialisation is the metallurgical industry; 2) increasing competition in various industries in world markets; 3) the impact of scientific and technological progress on the volume and structure of traffic; 4) suboptimal structure of exports, as explained by the raw material orientation of the economy. The first three reasons we attribute to environmental factors, the impact of which is difficult to manage and predict. The study of the flow of the fourth group of reasons is the subject of this study.

2 Research methods

This study uses structural modelling of enterprise performance indicators, particularly the volume of export cargo by railways of Ukraine in kind and value units for 2006-2020. This avoided the impact of inflation and other price factors on the results of further calculations. To assess the degree of structural uncertainty in the export of goods by the railways of Ukraine, the potential of the entropy index was used. The presence of structural uncertainty is due to the interaction of the main components: the dynamics of the structure of cargo turnover of export cargo by railways of Ukraine, the dynamics of the structure of revenues from export cargo by railways of Ukraine, and the dynamics of export cargo by railways of Ukraine for this period. The conducted economic interpretation of the category "entropy" made it possible to calculate the relevant indicators that indicate imbalances in the structure of export transportation.

3 Research results and discussion

The study of the problem of ensuring the sustainable development of railway transport in the part of export cargo transportation envisaged the choice of a suitable mathematical apparatus for the further optimisation of such strategically important activity for the state. Therefore, we have taken into account the achievements of scholars who have been studying the application of the entropy method in economics. The following achievements one may mention among them: i) it is proposed to evaluate the state of the economic national system using the developed methodology for quantification of the level of the orderliness of a complex economic systems system (Parshyn, 2015); ii) structural modelling of the product portfolio of the enterprise as a multicriteria task of optimisation of a complex dynamic system using the entropy index is realised; iii) the features of emergence and evaluation of entropy that can arise in the production and economic activity of the enterprise are investigated (Deineha & Deineha, 2018); iv) entropy theory is applied to different processes and systems; v) an algorithm for calculating the index of structural fluctuations (entropy) in the economy is proposed; and vi) characteristics that are inherent in the enterprise from the position of entropy are studied.

The term "entropy" is interpreted as the uncertainty through which there is realised disorder of the system and the incompleteness of information about the system (Budnikova, 2012). The entropy in the Shannon formula (Shannon, 1948) is an average characteristic – a
mathematical expectation of the distribution of a random variable and it is used as a measure of information uncertainty. The entropy (H) and the amount the information obtained by removing the uncertainty (I) depends on the initial number of variants (N) and the a priori probabilities of realisation of each of them (P), i.e. $H = F (N, P)$.

In this case, the entropy is calculated using the Shannon formula proposed in 1948 in the paper "The Mathematical Theory of Communication" (Shannon, 1948):

$$H(X) = - \sum_{i=1}^{n} p(x_i) \log_b p(x_i)$$  \hspace{1cm} (1)

The minus sign is used because the logarithm of numbers less than 1 is negative.

But as $- \log a = \log \frac{1}{a}$ the formula can be written as:

$$H(X) = \sum_{i=1}^{n} p(x_i) \log_b \frac{1}{p(x_i)}$$  \hspace{1cm} (2)

Let’s use the following entropy interpretation for this research: the entropy is a measure of the structural uncertainty of export cargo transportations by Ukrainian railways.

This structure is due to the following main components: the dynamics of turnover of export cargo transportations by railways of Ukraine, the dynamics of revenues from the export cargo transportations by railways of Ukraine, and the dynamics of volumes of transportations of export cargoes by railways of Ukraine.

The entropy is an indicator of the degree of disorder of the system, that is, a measure of chaos, so it must be as small as possible to ensure the requirement for sustainable development of railway transport enterprises.

It is necessary to use the mathematical programming apparatus to achieve optimal values of the structure of exports according to a certain system of indicators, which will provide a minimum value of entropy.

Formulation of the problem will look as follows:

$$Z_1(W_{1j}) \rightarrow min,$$  \hspace{1cm} (3)
$$Z_2(W_{2j}) \rightarrow min,$$  \hspace{1cm} (4)
$$Z_3(W_{3j}) \rightarrow min,$$  \hspace{1cm} (5)

where $Z_i$ – entropy of the structure of cargo turnover of export cargo transportation by railways of Ukraine;

$Z_2$ – entropy of the structure of revenues from export cargo transportations;

$Z_3$ – entropy of the structure of volumes of export cargo transportations.

The "minimum of entropy of export structure" is the criterion for optimisation of this objective function.

The system of limitations for this task is as follows:
where $W_{1j}$ – the average share of the j-th type of cargo in turnover of export cargo transportations by railways of Ukraine in researched period;

$W_{2j}$ – average share of the j-th type of cargo in the structure of revenues from export cargo transportations in researched period;

$W_{3j}$ – average share of the j-th type of cargo in the structure of volumes of export cargo transportations in researched period;

$j$ – index of the type of cargo ($j = 1, 18$);

$W_{1jmin}$ – minimum value of the j-th share of turnover of export cargo transportations by railways of Ukraine in researched period;

$W_{2jmin}$ – minimum value of the j-th share in the structure of revenues from export cargo transportations in researched period;

$W_{3jmin}$ – minimum value of the j-th share in the structure of volumes of export cargo transportations in researched period;

$W_{1jmax}$ – maximum value of the j-th share of turnover of export cargo transportations by railways of Ukraine in researched period;

$W_{2jmax}$ – maximum value of the j-th share in the structure of revenues from export cargo transportations in researched period;

$W_{3jmax}$ – maximum value of the j-th share in the structure of volumes of export cargo transportations in researched period.

The range (see formulas 6-8) indicates the probable limits of variation of share of j-th type of cargo by year.

In the restrictions, we made the assumption that the values of shares should be not less than the corresponding minimum value for the 12 studied years and not exceed their maximum value.

Let’s solve the problem using Microsoft Excel 2010 Office (Solver tool).
The evolutionary search for a solution for non-smooth optimisation problems is chosen as the solution method. As a result of the optimisation, we obtained an optimised structure of export cargo transportation, which ensures the achievement of the optimisation criterion, which is presented in a systematic form in (Tab. 1). The blue highlighted elements characterise the negative deviations of the results after optimisation of the corresponding structure from indicators before optimisation. As one can see, such reductions in the structure are characteristic of the 3 studied indicators. Such values of the structure of export after optimisation should ensure the sustainability of the development of the railway industry. Graphical illustration of the results of the calculations (Fig. 1-3) allows us to establish the similarity of the optimised structure by the selected criteria.

### Table 1 | The structure of cargo turnover, revenues from transportation, volumes of export cargo transportations by railways of Ukraine before and after optimisation

<table>
<thead>
<tr>
<th>Name of cargo</th>
<th>The structure of turnover of export cargo transportations</th>
<th>Deviation</th>
<th>The structure of revenues from export cargo transportations</th>
<th>Deviation</th>
<th>The structure of volumes of export cargo transportations</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>before optimization</td>
<td>after optimization</td>
<td>before optimization</td>
<td>after optimization</td>
<td>before optimization</td>
<td>after optimization</td>
</tr>
<tr>
<td>Total for kind of cargo</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.0000</td>
<td>1.0000</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>Stone coal</td>
<td>0.0316</td>
<td>0.0082</td>
<td>-0.0234</td>
<td>0.0257</td>
<td>0.0050</td>
<td>-0.0207</td>
</tr>
<tr>
<td>Oil and petroleum products</td>
<td>0.0081</td>
<td>0.0007</td>
<td>-0.0074</td>
<td>0.0310</td>
<td>0.0014</td>
<td>-0.0296</td>
</tr>
<tr>
<td>Iron and manganese ores</td>
<td>0.3483</td>
<td>0.4317</td>
<td>0.0834</td>
<td>0.2260</td>
<td>0.2685</td>
<td>0.0425</td>
</tr>
<tr>
<td>Colored ores and sulfur raw materials</td>
<td>0.0142</td>
<td>0.0096</td>
<td>-0.0046</td>
<td>0.0139</td>
<td>0.0100</td>
<td>-0.0039</td>
</tr>
<tr>
<td>Ferrous metals</td>
<td>0.1560</td>
<td>0.2508</td>
<td>0.0949</td>
<td>0.2405</td>
<td>0.2377</td>
<td>-0.0029</td>
</tr>
<tr>
<td>Non-ferrous metals and wares from them</td>
<td>0.0001</td>
<td>0.0000</td>
<td>-0.0001</td>
<td>0.0004</td>
<td>0.0000</td>
<td>-0.0004</td>
</tr>
<tr>
<td>Timber cargo</td>
<td>0.0200</td>
<td>0.0081</td>
<td>-0.0119</td>
<td>0.0244</td>
<td>0.0095</td>
<td>-0.0149</td>
</tr>
<tr>
<td>Chemical and mineral fertilizers</td>
<td>0.0225</td>
<td>0.0055</td>
<td>-0.0171</td>
<td>0.0213</td>
<td>0.0043</td>
<td>-0.0170</td>
</tr>
<tr>
<td>Chemicals</td>
<td>0.0128</td>
<td>0.0059</td>
<td>-0.0070</td>
<td>0.0297</td>
<td>0.0121</td>
<td>-0.0176</td>
</tr>
<tr>
<td>Cars</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0003</td>
<td>0.0000</td>
<td>-0.0003</td>
</tr>
<tr>
<td>Machines and equipment</td>
<td>0.0008</td>
<td>0.0003</td>
<td>-0.0005</td>
<td>0.0053</td>
<td>0.0013</td>
<td>-0.0040</td>
</tr>
<tr>
<td>Grain and grinding products</td>
<td>0.1133</td>
<td>0.0353</td>
<td>-0.0780</td>
<td>0.1768</td>
<td>0.3057</td>
<td>0.1288</td>
</tr>
<tr>
<td>Coke</td>
<td>0.0070</td>
<td>0.0019</td>
<td>-0.0051</td>
<td>0.0126</td>
<td>0.0023</td>
<td>-0.0104</td>
</tr>
<tr>
<td>Ferrous metal scrap</td>
<td>0.0003</td>
<td>0.0000</td>
<td>-0.0006</td>
<td>0.0011</td>
<td>0.0001</td>
<td>-0.0010</td>
</tr>
<tr>
<td>Mineral building materials</td>
<td>0.1426</td>
<td>0.1977</td>
<td>0.0551</td>
<td>0.0881</td>
<td>0.0614</td>
<td>-0.0268</td>
</tr>
<tr>
<td>Cement</td>
<td>0.0017</td>
<td>0.0006</td>
<td>-0.0011</td>
<td>0.0021</td>
<td>0.0005</td>
<td>-0.0016</td>
</tr>
<tr>
<td>Salt</td>
<td>0.0119</td>
<td>0.0057</td>
<td>-0.0062</td>
<td>0.0076</td>
<td>0.0032</td>
<td>-0.0044</td>
</tr>
</tbody>
</table>
Other cargoes 0.0458 0.0366 -0.0091 0.0930 0.0753 -0.0178 0.0461 0.0365 -0.0096
Source: author’s elaboration

Figure 1 | The structure of turnover of export cargo transportations by Ukrainian railways by type before and after optimisation

Source: author’s elaboration
Figure 2 | The structure of revenues from export cargo transportations by Ukrainian railways by type before and after optimisation

Source: author’s elaboration

Figure 2 | The structure of volumes of export cargo transportations by Ukrainian railways by type before and after optimisation

Source: author’s elaboration
Therefore, according to the optimised structure, it would be advisable:

1) to reduce the values of cargo turnover, revenues from export cargo transportations and volumes of export cargo transportations for such cargoes – stone coal; oil and petroleum products; coloured ore and sulfur raw materials; non-ferrous metals and wares from them; timber cargo; chemical and mineral fertilisers; chemicals; machines and equipment; coke; ferrous metal scrap; cement; salt; other cargoes.

2) to increase indicators of cargo turnover, revenues from export cargo transportations and volumes of export cargo transportations for iron and manganese ores by 8.34%, 4.25% and 9.35%, respectively.

3) for the other 4 types of cargo (ferrous metals, cars, grain and grinding products, mineral building materials), the optimised values of these 3 indicators had both positive and negative deviations. Therefore, for grain and grinding products, according to the optimisation model, it is recommended to reduce the volume of transportations and cargo turnover by 7.8% and 11.18% and to increase the revenues from the export of this type of cargo by 12.88%; for ferrous metals and mineral building materials, on the contrary, it is necessary to increase the volume of transportations and cargo turnover but to reduce the share of revenues from this type of transportations.

The results of the calculations were generated by the Solver tool in the form of a "Report on results". Provided that the structure is optimised for cargo turnover, revenues and volumes of transportation by type of cargo, a decrease in the entropy index is achieved as a requirement of sustainable development. The systematised calculated values of this indicator are presented in Tab. 2.

**Table 2 | The calculated values of the entropy indicators**

<table>
<thead>
<tr>
<th>Indicators of entropy</th>
<th>Value</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnover of export cargo transportations</td>
<td>( Z_1 )</td>
<td>before optimization</td>
</tr>
<tr>
<td></td>
<td>( Z_1 )</td>
<td>after optimization</td>
</tr>
<tr>
<td>Revenues from export cargo transportations</td>
<td>( Z_2 )</td>
<td>before optimization</td>
</tr>
<tr>
<td></td>
<td>( Z_2 )</td>
<td>after optimization</td>
</tr>
<tr>
<td>Volumes of export cargo transportations</td>
<td>( Z_3 )</td>
<td>before optimization</td>
</tr>
<tr>
<td></td>
<td>( Z_3 )</td>
<td>after optimization</td>
</tr>
</tbody>
</table>

Source: author's elaboration

As can be seen from Table 2, the largest reduction in the entropy indicator can be obtained by optimising the structure of volumes of export cargo transportations because this indicator has almost halved after optimisation. Therefore, this structure can be considered as a reference for further use in the analytical activity and in making appropriate management decisions at JSC "Ukrzaliznytsia".

As for the optimisation tools used by various scholars in the study of this problem, there were classical and adapted integer programming methods. This choice is due to the specificity of the proposed optimisation criteria, variables in the models – integers or binary variables that indicate the solution. In the studied models, the indicator of the export cargo transportation system state was not used as a criterion of optimisation to measure the balance of this system.

In contrast to the existing approaches to optimisation in the field of export transportation, we propose modelling based on a set of target functions with the criterion of optimisation –
"minimum entropy", which allows establishing the degree of balance of the system structure and the corresponding system of constraints. This model complex was practically implemented to optimise JSC "Ukrzaliznytsia" export freight while maintaining existing trends. Distinctive features of the study are: 1) the use of sectoral indicators (mesoeconomics level) for the transport sector (existing research in the field of entropy analysis, mainly focused on microeconomic or macroeconomic levels); 2) the potential of entropy analysis in the field of structural optimisation is revealed to a greater extent.

That's worth underlining that based on the sporadic phenomenon of Brexit, Fernandes and Winters (2021) stated that the shock of the referendum had a negative impact on Britain's export potential and reduced the likelihood of its growth. In contrast to this approach, our study presents the concept of a dynamic approach based on a more traditional scientific paradigm. This traditional approach is typical for many studies. In particular, the methodology presented by Zhang et al. (2016), which uses binary variables to achieve the criterion of optimisation of the maximum comprehensive preference of shippers to transport attributes, uses similar approaches to our study. However, we have chosen the minimum entropy as a criterion for optimisation to measure the disorder of the export structure system. In turn, the study of Dobrodey et al. (2018) proposed an imitation forecast of railway system operation in a macroregion using a similar scientific paradigm, which is based on a dynamic approach but without considering system status indicators. The results of our study differ in the entropic approach to identify the state of the export structure of the transport company.

Conclusions

Our study showed the prospects for the application of optimisation of structures for scientific support of planning activities in transport companies. From the scientific point of view, our study made it possible to develop an algorithm for structural modelling of enterprise performance indicators using entropy characteristics. One of the main stages of this algorithm is the structural and dynamic analysis of the object of study, which allows identifying and systematising the main factors that affect the structure of export rail transport. The proposed algorithm of entropy analysis can serve as a value of imbalances in the structure of complex systems.

The result of the practical application of the proposed algorithm on the example of JSC "Ukrzaliznytsia" is an optimised structure of export freight. Eighteen names of cargoes transported by Ukrainian railways for export, according to optimisation calculations, have quite similar structures by year. However, the comparison of entropy values by three indicators (freight turnover, revenues, and volumes) allowed choosing the optimal export structure by volume. The entropy index double reduction of volumes (as an indicator of export structure imbalances) for the period under study can be obtained due to the optimisation of the structures of export cargo.

The results of the structural modelling are a reference point for the structure of transportation, which can serve as a basis for planning in the relevant field (railway infrastructure, volume, and quality indicators of transport work) for scientific support of the railway transport of Ukraine. Also, the use of structural modelling will facilitate the adoption of such management decisions that trigger the mechanism of synergistic interaction of structural indicators of different economic entities. For further explorations, it is proposed to
study the quantitative impact studied structure on the activities of the railway industry and the economy as a whole.

Limitations in such a study may be the presence of a significant statistical database for at least ten periods, during which the methodology of statistical data collection was comparable in time. It cannot serve as a benchmark for implementation but is used at the information analysis stage for decision making. The obtained results of structural modelling have a recommendatory character and are not a variant of the final management decision on the structure of exports.

References


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