Enhancing Railway Section Capacity, during Expansion of the European Railway Network

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Abstract: The Trans-European Transport Network was established by the European Union to connect Europe from west to east and north to south through a transportation network. One of the challenges in organizing barrier-free railway connections across European countries is the varying track gauge. Some European countries continue to use gauges different from 1435 mm. The aim of this study is to provide a scientific justification for reconstruction options, for a railway section, taking into account technical, economic, and other aspects, as well as to develop recommendations for a successful transition to European track standards. In this work, the authors examined the Kovel-Sarny-Korosten section, which is part of the Warsaw-Kyiv route. This route is one of several options for upgrading to European gauge to create a continuous railway network between the European Union and Ukraine. The research methodology and scientific approaches may vary depending on the characteristics of the sections being considered. In this study, the authors implemented the following sequence of steps: determined the maximum freight capacity for each segment, assessed the existing capacity, analysed reconstruction measures, and evaluated the effectiveness of reconstruction options. The modernization of the railway corridor under consideration has significant potential to improve transport connectivity between Ukraine and Poland, as well as to stimulate economic development in the regions through which this route passes.

Keywords: railway; transport corridor; track gauge; capacity per section; Net Present Value

1 Introduction

The Trans-European Transport Network (TEN-T) was established by the European Union to connect Europe from west to east and from north to south with a network of highways, railways, airports, and waterways. The foundation of TEN-T consists of nine multimodal corridors, which link the transport networks of 28 EU member states and include railways, rail terminals, highways, inland waterways, river and sea ports, and airports [1].

One of the challenges in organizing barrier-free railway connections across all European countries is the difference in track gauges. Some European countries continue to use a track gauge different from the standard 1435 mm. For instance, in Lithuania, Latvia, and Estonia, the 1520 mm gauge remains in use on most sections. The Baltic countries see the construction of new railway sections to European standards within the framework of the "Rail Baltica" project as one solution to this issue [2] [3].

Although the majority of Finland's railway network uses the broad gauge (1520 mm), a transition to European standards is being considered as part of the development of transport corridors between Finland and Central Europe [4] [5].

Moldova is also considering a transition to European track gauge standards in the context of integrating into EU transport corridors and facilitating transportation to Romania and other European countries [6].

For Ukraine, the issue of integrating its transport infrastructure with the European network has gained particular relevance in light of strengthening economic and political ties between Ukraine and the European Union. Railway transport is one of the key components of this integration, as it provides efficient long-distance transportation for both passengers and goods. Of special importance is the transition of Ukraine's railway network to the European track gauge (1435 mm), which will not only increase border capacity but also simplify logistics processes [7] [8].

Portugal and Spain use the broad Iberian gauge of 1668 mm. While the issue of fully transitioning to the European gauge is not as critical for them as it is for Eastern European countries, it is still relevant for the development of high-speed rail transport and the improvement of international freight operations, particularly for integration with neighbouring countries such as France, which uses the standard European gauge [9].

The purpose of this study is to scientifically substantiate the options for reconstructing the railway section, taking into account technical, economic, and other factors, as well as to develop recommendations to ensure a successful transition to the European gauge. Particular emphasis is placed on the importance of this project not only for Ukraine but also for EU countries, as it will contribute to the development of the pan-European transport network and strengthen economic cooperation between nations.

2 Methods

The research methodology and scientific approaches may vary depending on the characteristics of the sections being considered. In this study, the authors implemented the following sequence of steps: determining the maximum freight capacity for each segment, assessing the existing capacity, analyzing reconstruction measures, and evaluating the effectiveness of reconstruction options.

2.1 Determination of Maximum Carrying Capacity

The carrying capacity of railway sections is determined by the equation:

$$G = \frac{365 n_c Q}{\gamma} 10^{-6} \quad (1)$$

where Q is the average net weight of the train in tons; n_c is the number of freight trains (in pairs per day); γ is the coefficient of transport unevenness, ranging from 1.05 to 1.15.

The average train weight is calculated using the equation:

$$Q = Q_{un}\eta\mu \quad (2)$$

where Q_{un} is the unified train weight standard, which is accepted for the entire route and is selected based on one or several sections that limit the carrying capacity; η is the coefficient accounting for wagon tare weight (0.70–0.74); μ is the coefficient reflecting the structure of the freight flow (0.80–0.90).

The number of freight trains is calculated by the equation:

$$n_c = n_{max}(1-p) - E_p n_p - E_m n_m + n_m \quad (3)$$

where n_{max} is the capacity of single-track sections (in train pairs); p is the reserve capacity coefficient (0.15–0.20); E_p, E_m are the removal coefficients for passenger and mixed trains; n_p, n_m are the number of passenger and mixed trains, respectively.

The capacity of single-track sections (in train pairs) with a parallel timetable is determined by the equation:

$$n_{max} = \frac{(1440 - t_{tech})\alpha}{T} \quad (4)$$

where t_{tech} is the duration of the technical window (60 minutes); α is the reliability coefficient that accounts for the impact of failures in technical systems (such as tracks, signalling and communication devices, or the contact network) on the available railway capacity (0.96); and T is the timetable period in minutes.

2.2 Assessment of Existing Capacity

The existing capacity for freight traffic can be calculated if the train travel time on the most challenging section, the number of passenger and other trains, as well as the type of signalling and communication systems and the transportation process technology, are known. An accurate assessment of this parameter allows for the efficient use of railway infrastructure and ensures high-quality transport services.

2.3 Reconstruction Measures

The reconstruction of railway sections during the transition from national to European track gauge may involve a variety of technical and structural measures. These can range from the construction of a new railway track [7], which essentially goes beyond the scope of merely reconstructing an existing section, to transitioning one of the tracks on double-track sections to the European standard, replacing the existing track with the European gauge, or laying mixed-gauge tracks [8].

Such changes to track design typically require additional work to ensure the clearance dimensions for the modified infrastructure [10]; the implementation of major repairs to restore track conditions; the electrification of sections if necessary; and the replacement of signalling and communication systems [11]. Further measures might include strengthening the ballast layer [10] [12] and the subgrade [13] [14].

The list of these measures is not always straightforward. It depends on the operating conditions and structural characteristics of specific railway sections. In most cases, the choice of reconstruction measures requires a technical and economic justification from a set of possible options.

2.4 Evaluation of Reconstruction Efficiency

For comparison of the options, the criterion of Net Present Value (*NPV*) was adopted in this work, which is widely used in global practice [15] [16].

The authors have developed a model for forecasting and assessing the efficiency of railway transportation, taking into account all costs using the indicator NPV_t, which represents the difference between total revenue D_t and all types of expenses, with consideration of the time factor *t*. These include investments Ki, expenses for the locomotive fleet Kl, wagon fleet Kc, current operating costs C, costs depending on the type of technological operations, and the time freight and passenger wagons spend on station tracks Cs, and discount coefficient η [17]:

$$NPV_t = (D_t - Ki_t - Kl_t - Kc_t - C_t - Cs_t)\eta_t, \quad (5)$$

The cumulative net present value consists of the revenue from passenger $NPV(pas)$ and freight $NPV(car)$ transportation over the calculation period of 15 years:

$$NPV = \sum_{t=1}^{T} NPV(pas)_t + \sum_{t=1}^{T} NPV(car)_t. \quad (6)$$

3 Results and Discussion

In this work, the authors examined the Kovel-Sarny-Korosten section, which is part of the Warsaw–Kyiv route. This route is one of several options for conversion to European gauge to create a continuous railway network between the European Union and Ukraine [7]. The Kovel-Sarny-Korosten section has a total length of approximately 300 km. It is a single-track section with diesel traction. The layout of the section is shown in Fig. 1.

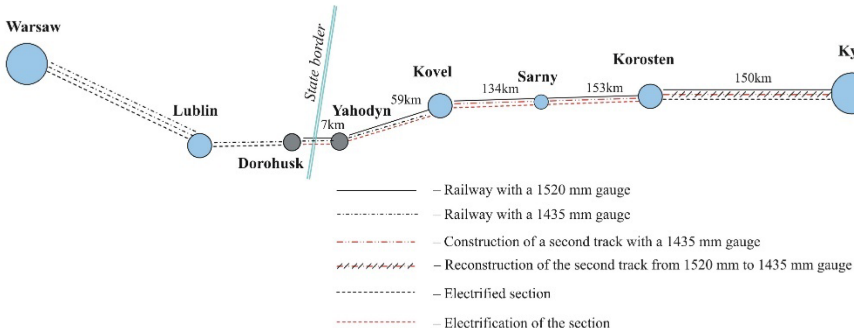

Figure 1
Reconstruction of the Warsaw–Kyiv route

The section is equipped with R65-type rails, jointed track, concrete sleepers, ballast made of crushed stone on a sand cushion, and KB-type fasteners. The dominant feature of the subgrade is the embankment, which constitutes about 95% of the section. For the embankment construction, second-group soils from surveyed quarries and cuts were used. The maximum embankment height reaches about nine meters, while the cuts are as deep as six meters. The width of the main subgrade platform is seven meters. Among the sections included in the Kovel-Sarny-Korosten route, the Kovel-Sarny section is the most challenging, both in terms of slope gradients and curve radii.

To determine the maximum capacity of the section, traction calculations were carried out for diesel traction using the 2M62 locomotive [18]. The mass of the freight train varied from 2000 to 4000 tons. The capacity was calculated using Eq. (1), and the results are presented in Figs. 2-4.

The capacity analysis (Figs. 2-4) shows that with a train weight of 4,000 tons, the lowest capacity on the Kovel-Sarny section occurs on the Kovel-Povursk segment, with 19 train pairs per day. The Antonivka-Sarny and Rafalivka-Antonivka segments have slightly higher minimum capacities, at 20 train pairs per day. On the Sarny-Olevsk section, the lowest capacity is on the Ostky-Olevsk segment, with 24 train pairs per day, while on the Olevsk-Korosten section, the Bilokorovychi-Kremno segment sees 21 train pairs per day. Thus, the Kovel-Sarny section is the most critical due to its challenging profile and layout parameters.

Regarding a 4000-ton train, the Kovel-Korosten route features steep gradients, where the minimum speed can fall below the allowable limit of 20 km/h.

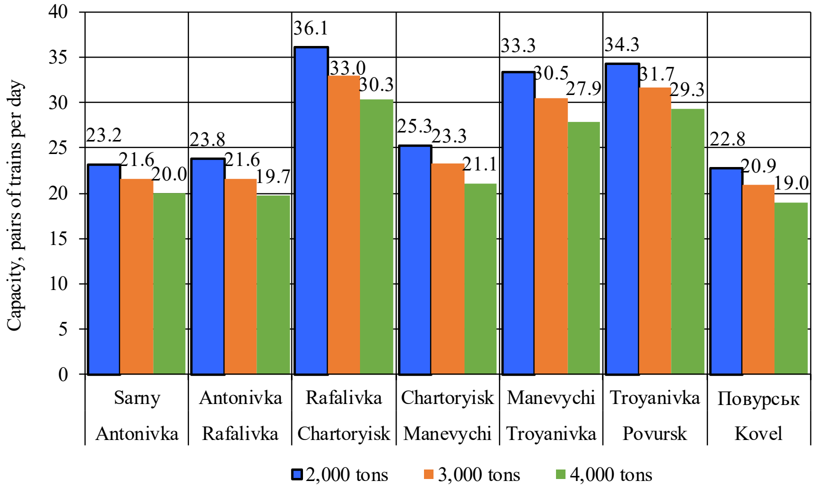

Figure 2
Capacity per section on the Kovel-Sarny route

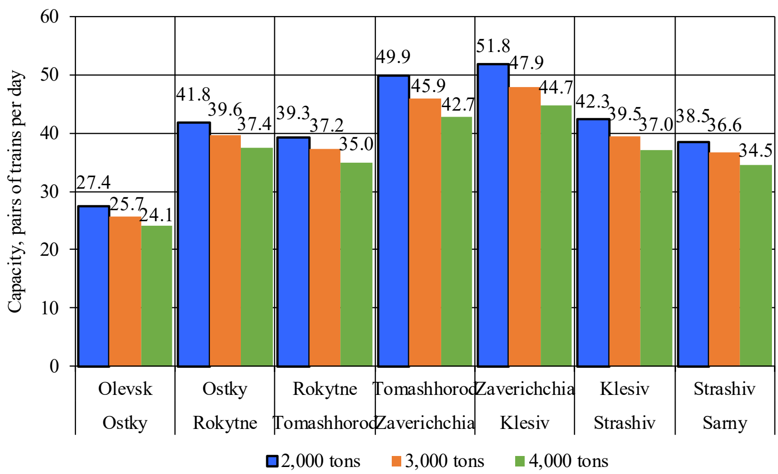

Figure 3
Capacity per section on the Sarny-Olevsk route

According to train schedule standards, trains with a weight of 4000 tons can pass through stations such as Dibrova-Olevska and Luhyny at around 60 km/h without stopping when traveling in the paired direction. In the unpaired direction, trains weighing up to 5100 tons can operate with the use of a helper locomotive on the Bilokorovychi-Dibrova-Olevska segment.

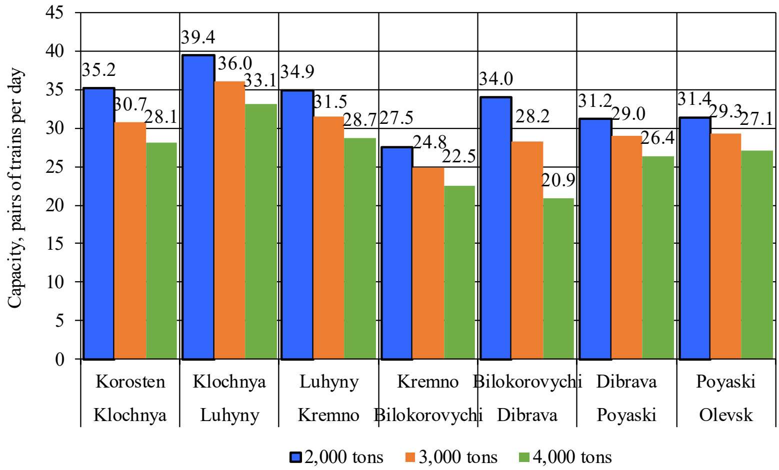

Figure 4

Capacity per section on the Olevsk-Korosten route

The development program for the 1435 mm track gauge railway network includes the technical and economic justification of various technical, technological, and organizational solutions. It also outlines the construction of 1435 mm gauge hubs/terminals (Lviv, Uzhhorod, Chop, Kovel, Kyiv, Chernivtsi), the capital overhaul of the 1435 mm track on the Kovel-Yahodyn-border section, and the reconstruction of railway structures with the electrification of the Kovel-Yahodyn-border route with Poland.

The electrification project "Kovel-Yahodyn-Border" will have a significant social impact, as it will enable the launch of Intercity passenger trains to Kovel station, which connects with all major hub stations in Ukraine. This project will facilitate direct railway connections between Ukraine and the European Union [19].

Taking into account the planned tasks and developments, the authors have proposed a scheme for implementing the above-mentioned measures (Fig. 1).

The implementation of the Warsaw-Kyiv route will enable direct train services from Poland to Ukraine without the need for transfers. Necessary measures include the construction of a second track on the Kovel-Sarny-Korosten section (300 km) with a 1435 mm gauge, and the electrification of the Dorohusk-Kovel-Sarny-Korosten railway section (360 km, 1435 mm gauge). One of the main drawbacks is the significant investment required, which would only be recouped through high volumes of passenger and freight traffic.

The reconstruction of the railway for the 1435 mm gauge will eliminate the current bottleneck – the gauge-changing facility at Yahodyn station. The capacity of the single-track line depends on the train travel time in both directions and the station interval times.

Considering that the Kyiv-Korosten section is electrified and the Kovel-Yahodyn section is planned to be electrified according to the project, the authors examined the prospects of transitioning from diesel traction to electric traction on the Kovel-Sarny-Korosten section and analysed how the introduction of electric traction affects the increase in freight train mass and overall transport capacity.

To assess the efficiency of electric traction compared to diesel traction, traction calculations were performed, train travel time was obtained, and the transport capacity was calculated. A comparison of segmental transport capacity for the 2M62 and 2EL5 locomotives [20] with a train mass of 4000 tons is shown in Fig. 5.

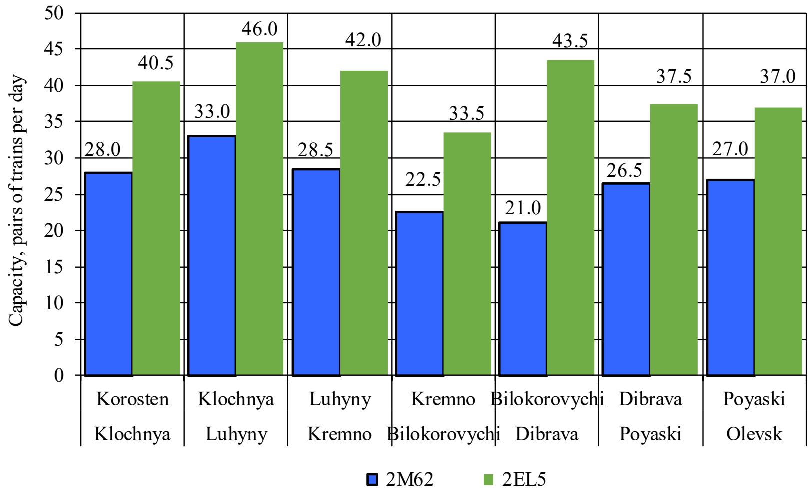

Figure 5

Capacity per section for diesel and electric traction

From Fig. 5, it follows that the bottlenecks in transport capacity are the Bilokorovychi-Dibrova and Kremno-Bilokorovychi sections. With diesel traction, the maximum capacity is 21 train pairs per day, while with electric traction, it increases to 33.5 train pairs, a 1.5 to 2 times increase.

According to the proposals [1], the new 1435 mm gauge mainline network will be used for international passenger trains and for transporting freight in containers or on platforms.

To determine the number of freight trains (pairs of trains per day), Eq. (3) is applied. For preliminary calculations, the reserve capacity coefficient is taken as *p*=0.15, with 2-8 passenger trains (n_p) and a removal coefficient of E_p=1.5.

From Eq. (1):

$$n_c = \frac{G\gamma}{365Q} 10^6 \qquad (7)$$

By combining equations (3) and (7), the freight traffic volumes were determined given the known maximum capacity n_{max} and the specified number of passengers n_p:

$$G = \frac{365Q(n_{max}(1-p)-E_p n_p)}{\gamma}10^{-6} \qquad (8)$$

The calculation results obtained using Eq. (8) are presented as graphs in Fig. 6.

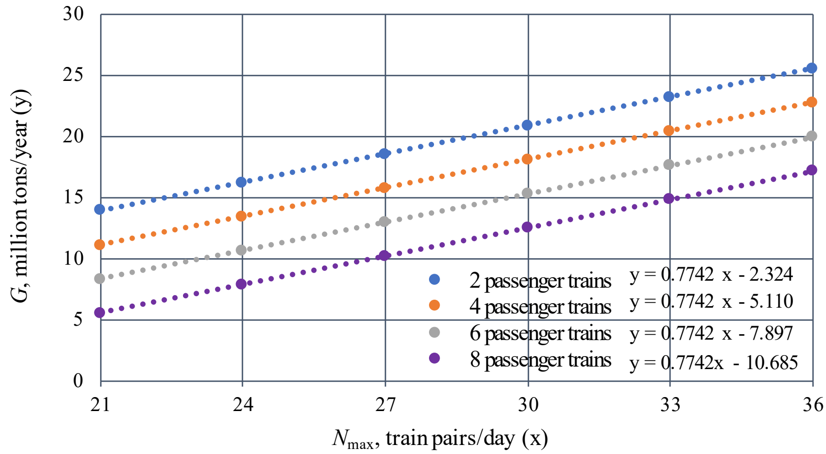

Figure 6

Freight capacity depending on maximum capacity and the number of passenger trains

The approximate cost of the options is provided in Table 1: the construction of the second main track – €8.0-10.0 million/km, electrification – €4.0-6.0 million/km, and the conversion of the second track from 1520 mm to 1435 mm – €3.0-4.0 million/km. Kyiv railway infrastructure with diesel traction is, on average, €3.2 billion. With the introduction of electric traction, the cost increases by 1.5 times.

Table 1

Reconstruction Measures on the Dorohusk-Kovel-Korosten-Kyiv Route

Necessary Measures	**Distance km**	**Cost billion euros**
Construction of a second track on the Kovel-Sarny-Korosten section with a track gauge of 1435 mm	298	2.4 - 3.0
Electrification of the Dorohusk-Kovel-Sarny-Korosten railway section (track gauge 1435 mm)	360	1.4 - 2.2
Conversion of the second track from a gauge of 1520 mm to 1435 mm on the Korosten-Kyiv section or installation of a combined track on one of the main tracks.	156	0.5 - 0.6

Assuming the maximum capacity of the route is 21 train pairs per day and the number of passenger trains is two pairs, the freight capacity from the graph (Fig. 6) is 14 million tons per year, which according to equation (1) corresponds to 15 pairs of freight trains per day. The value of the net present value (*NPV*) for the Warsaw-Kovel-Korosten-Kyiv route based on the above-mentioned input data is $\sum_{t=1}^{T} NPV(pas)_t$= –21.163 billion euros, $\sum_{t=1}^{T} NPV(car)_t$=7.239 billion euros.

It can be concluded that the implementation of mixed traffic on the Warsaw-Kyiv route, given the presence of single-track railways and diesel traction, is limited by capacity and the type of traction used. As established (see Fig. 1), the minimum capacity with electric traction is 33 train pairs per day. The calculation results based on Eq. (6) are presented in Fig. 7. Converting the railway to electric traction increases capacity and yields a positive effect in the form of net present value (*NPV*) at a freight flow of 21 million tons per year and 4 pairs of passenger trains, Fig. 7.

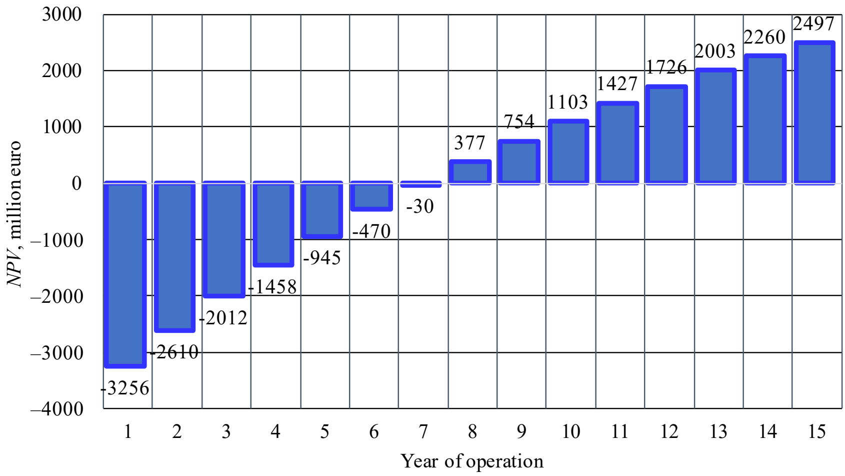

Figure 7
NPV distribution diagram for the Warsaw-Kovel-Korosten-Kyiv route

Conclusions

The modernization of the Kyiv-Sarny-Kovel-Border railway route, connecting to Warsaw, holds significant potential for improving transport links between Ukraine and Poland, as well as stimulating the economic development of the regions along this route.

To increase the capacity and throughput, while ensuring operational compatibility between Ukrainian and Polish railways (1435 mm gauge), the following reconstruction measures are recommended: construction of a second main track on the Kovel-Sarny-Korosten section with a 1435 mm gauge, and reconstruction of the second track from 1520 mm to 1435 mm on the Korosten-Kyiv section, or laying a dual-gauge track on one of the main lines.

Preliminary calculations have shown that the implementation of this project will require substantial investments. Given the low capacity (19-21 train pairs per day), organizing solely passenger services does not yield a positive economic effect. The introduction of combined services (passenger and container freight transportation) also does not generate profit. A solution to this issue could be the electrification of the Dorohusk-Kovel-Sarny-Korosten railway section (1435 mm gauge), which would increase the capacity to 33-35 train pairs per day and generate a net discounted income under the following transportation conditions:

- Passenger traffic – 4 train pairs per day
- Freight volume – 21 million tons per year

A final decision will require further economic research and an assessment of the prospective freight and passenger traffic volumes.

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