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LIFE CYCLE COST ANALYSIS OF EUROPE–ASIA TRANSPORTATION SYSTEMS

ANALIZA KOSZTU CYKLU ŻYCIA SYSTEMÓW TRANSPORTOWYCH EUROPA–AZJA

A b s t r a c t

The effectiveness of East-West rail transportation systems significantly depends on the track gauge change from 1435 mm to 1520 mm, which requires complicated handling-shifting operations. Comparative analysis of hazardous materials transport, among others using SUW 2000 system of self-adjusted wheel-sets, was based on the established effectiveness model (LCC analysis). The analysis pointed out both economic effects and the application's restrictions in assumed and presented variants.

Keywords: *LCC analysis*, *life cycle cost*, *track gauge change*

S t r e s z c z e n i e

Efektywność kolejowych systemów transportowych Wschód–Zachód zależy od zmiany szerokości torów 1435/1520 mm, wiążącej się ze złożonymi operacjami przeładunkowo-przestawczymi. Na podstawie przyjętego modelu decyzyjnego (analizy LCC) dokonano porównawczej analizy efektywności przewozu materiałów niebezpiecznych z zastosowaniem systemu SUW 2000 (samoczynnie rozsuwanych zestawów kołowych). Wykazano efekty ekonomiczne przyjętych wariantów oraz ograniczenia stosowania.

Słowa kluczowe: *analiza LCC, koszt cyklu życia*, *zmiana szerokości toru*

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1. Introduction

The development of the European economy mainly depends on efficiency of the Europe–Asia transport system which makes the connection of Russian, Korean and Chinese Pacific harbors with the West Europe possible. Assurance of effective conditions for realization of international cargo haulage is particularly difficult for the rail transportation. It is connected with various gauges existing in Europe and Asia continent. The majority of European countries, including Poland, have 1435 mm gauge tracks but the railways of the former Community of Independent States and the others, including Lithuania, Latvia and Estonia, have railways of 1520 mm gauge. In the territory of Asia, trains move on the wide gauge track (1520 mm), encountering the normal gauge (1435 mm) lines in China and Korea again. In Spain and Portugal, there are even wider at 1668 mm (Fig. 1).

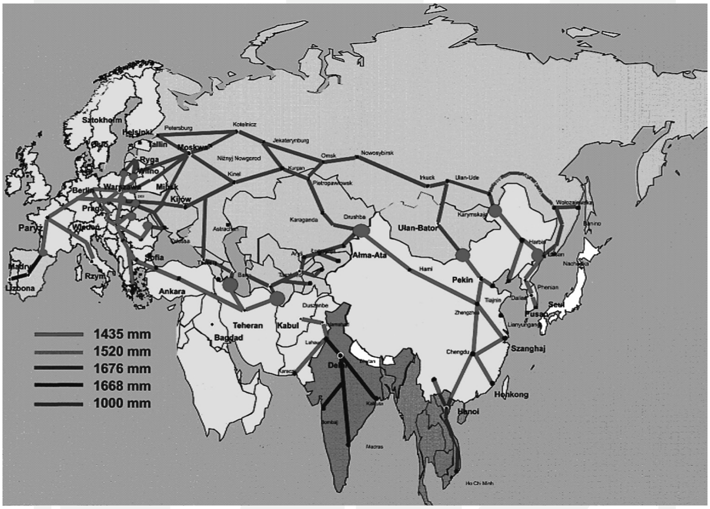

Fig. 1. Variety of the track gauge on the European-Asian continent [11]

Such differences seriously impede the operation as at the points where different gauges meet, the cargo must be either trans-shipped or the running assemblies of rail vehicles must be exchanged. Those operations are costly, time-consuming and require extended infrastructure together with very expensive storage and trans-shipment facilities at border-crossing points. Moreover, those operations extend transportation time considerably.

2. Infrastructure at the point of the track gauge change 1520/1435 mm

Cargo displacement in the transport system between Europe and Asia attains up to 15,000 km. It requires a specific type of service connected with a change of rail gauge. Two basic technologies of overcoming this problem are possible:
– handling technology,
– shifting technology.

Figure 2 presents possible techno-organizational variants for the both haulage technology.

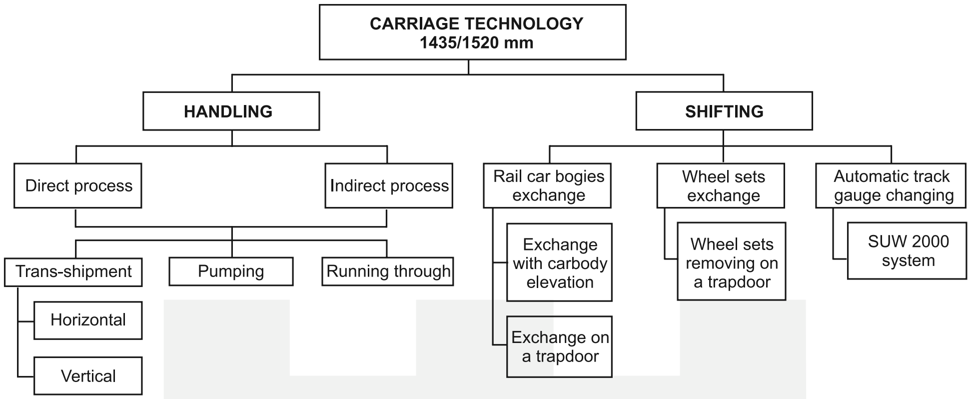

Fig. 2. Techno-organization variants of railway gauge change [6, 12]

Generally, the transhipment technology deals with transporting cargo at the meeting points of different gauge railways from the freight car of one gauge to the car of the other one. In that technology, depending on the kind of cargo, the following methods may be listed:
- reloading,
- pumping,
- pouring.

The shifting technology is realized shifting the mean of transport from one gauge to the other. It can be done in two ways:
- exchange of the vehicle running assemblies,
- self-adjusting wheel sets.

3. Decision models of transport systems evaluation

For effective evaluation of gauge change techniques, the following methods may be applied:
- Techno-Economics Analysis,
- Life Cycle Costs Analysis,
- Analytic Network Process.

Setting an appropriate undertaking evaluation criterion as well as application a right method of profitability account for taking proper investment decisions makes development trends charting of transport systems, haulage technologies and transport-logistics services possible. Selecting the undertaking effectiveness investigation methods worked out and applied until now depends on individual features of the enterprise.

Among the simple methods of financial assessment and discount methods the following may be applied for transport systems effectiveness analysis:

– payback period (PP),
– break-even point (BEP) analysis,
– net present value (NPV),
– internal rate of return (IRR).

Life-cycle costs (LCC) are total costs comprising three basic data sets dealing with costs of purchase, acquisition and possibly, liquidation. Each element of the data sets requires a detailed definition and description on the basis of operational, experimental data as well as data obtained by other means (e.g.: expert methods) [13]. The structure written out in detail makes possible the LCC costs to be used as:
– a decision basis for the organization of transport systems,
– making a decision concerning the system modernization and restructuring,
– a haulage technologies assessment criterion, a comparison possibility of different haulage technology variants,
– a basis for costs shaping of transport service.

The Analytic Network Process (ANP) also constitutes a multi-criterion decision making method called Saaty's method (after it's author) [10]. A structure of the problem is presented as a network constituting a system of objects in which relationships exist among object groups, objects inside that groups and reciprocal feedbacks as well.

4. Example of applying LCC analysis in effectiveness evaluation

As a part of the R&D projects [1–3] an effectiveness comparison of gauge change methods in the East-West system has been carried out for the following most important cargo groups:
– dangerous goods (petroleum products, liquefied gases),
– integrated unit loads (containers),
– package cargo,
– bulk cargo (iron ore).

For the above mentioned cargo groups, possible variants have been worked out and an effectiveness evaluation has been carried out.

As showed, the analysis of existing state dangerous goods (hazardous materials) haulage demands to be streamlined especially. The current solutions applied when gauge changing in the eastern border of Poland (gauge 1435/1520 mm) are not very effective for that kind of cargo, they also reduce safety and ecology of haulage. Moreover, according to the statistical data, hazardous materials constitute 30% of import and 13% of export cargo transported by rail in Poland. The introductory evaluation of the system effectiveness has been carried out using technical and economical indices. For detailed and complex evaluation, the LCC analysis has been applied [4, 5, 8, 9].

4.1. Assumptions and purpose of the LCC analysis

The LCC analysis of hazardous materials haulage in the east-west transport system has been carried out for two variants of track gauge change:
– variant 1, in which the haulage is realized with currently applied method of wagon bogie exchange,

– variant 2, in which the haulage is realized with the prospective method – the SUW 2000 system of self-adjusting wheel sets.

The analysis is of comparative character. An evaluation comparison of the costs generated in the phase of selected system variant operation has been accepted as a superior aim of the analysis. The following assumptions were accepted for constructing cost structures of the variants under analysis:

– haulage amount: 273,000 tons/year,
– wagon load capacity: tank car with a 50 ton load capacity,
– haulage distance: 1,100 km, it corresponds to the real relations of hazardous materials haulage: Odessa (Ukraine) Harbor – refineries on the South of Poland (for petroleum haulages); Mazeikiu Refinery (Lithuania) – LPG Distribution Center in Poland (for liquefied gas haulages) (Fig. 3).

Fig. 3. The marked out transport relations in hazardous materials haulage

4.2. Comparison of service process in analyzed variants

An LCC analysis without identification of service process in the contact points of different gauge tracks is unfeasible. In Table 1, some parameters characterizing a service process of selected variants are presented. The parameters are obtained from a techno-organizational evaluation.

Table 1

Characteristics of service process in border points for variant 1 and 2 [3, 4]

Variant	Shift group	Equipment of the border point	Mean shifting time	Mean time of the shift group exchange	Number of groups per 24 hours	Shifting capability per 24 hours
	[wagons]	[–]	[min]	[min]	[–]	[wagons]
1	10	10 stands with elevators	200	25	3	30
2	30	Gauge changing facility	6	25	46	1380

Taking into consideration service time and the capability resulting from the time, the variant 2 with self-adjusted wheel sets is unrivalled. However, in that case some limitations connected with service universality appear. Such technology requires either full train load haulages or initial switching before the point 1435/1520 mm [6, 7].

4.3. System breakdown structure and LCC model development

Common elements, which have the same influence in both system variants for example railway infrastructure, locomotives, etc., were eliminated from the calculation with regards to comparative character of analysis (Table 2).

Table 2

Elements of structure in analyzed variants

Analyzed variant	Element of system structure (units)			
	Label	Applied to rolling stock	Label	Applied to point 1435/1520 mm
Variant 1	1.1	Freight bogies for 1435 mm (106)	1.3	Gantry crane (3)
	1.2	Freight bogies for 1520 mm (106)	1.4	Stand with elevators (14)
Variant 2	2.1	Freight bogies with self-adjusted wheel sets of SUW 2000 system (80)	2.2	Track gauge changing stand of the SUW 2000 system (1)

LCC costing was preceded by dependability analysis RAM (Reliability, Availability, Maintainability) for all elements marked out in both variants. Among the most important dependability factors determined were:

- failure intensity $z(t)$,
- mean time between failure MTBF,
- mean up time MUT,
- mean accumulated down time MADT,
- mean time to restore MTTR,
- mean availability A and others.

RAM analysis required having dependability tests in order to gather and transform the indicated operation information.

For variant 1, in which transport of dangerous materials is conducted at the currently applied bogies exchange, operation data were gathered in the biggest point of bogies exchange Polish freight carrier PKP Cargo SA. This point is situated at the rail border Medyka/Mostiska (Poland/Ukraine) in III Pan-European transport corridor. For variant 2, dependability data were gathered as part of the economic monitored operation of the SUW 2000 system, held by PKP Cargo between Poland and Lithuania.

The indicated dependability parameters connected with reliability, durability, maintainability and availability constitute the definition of cost elements base in LCC models. The analysis has a comparative character, so all categories, which are the same for both variants, have been excluded from the cost model. This assumption makes the cost structure much more simple. The LCC model was developed on investments and acquisition costs (1). A period of twenty-five years of operation (2010–2034) has been assumed for analysis.

$$LCC = INC + AQC \tag{1}$$

where:

INC – investments costs,
AQC – acquisition costs.

Investments costs are the sum of capital investments which are necessary for transport's carrying out in analyzed variants of system. Acquisition costs constitute both maintenance and operational costs (2).

$$AQC = MC + OC = (PMC + CMC) + (POC + UNC) \tag{2}$$

where:

MC – maintenance costs,
PMC – preventive maintenance costs,
CMC – corrective maintenance costs,
OC – operation costs,
POC – operation personnel costs,
UNC – unavailability costs.

Elements' costs valuation is based on constant prices in euros (EUR) from 2010. Due to the limited range of the article, all mathematical formulas that were used to calculate cost elements are described in the reference [6].

4.4. Analysis of LCC model and effectiveness evaluation

Analyses of prepared models were conducted with CATLOC software. The calculations conducted for carrying hazardous materials in chosen transport relation of 1,100.0 km presented that applying variable-gauge wheel sets SUW 2000 ensure much higher effectiveness in comparison to currently used bogie exchange. LCC for variant 2, in 25 years-operation--system, is 3.62 mln EUR or 20.8% lower than in variant 1 (Fig. 4a). The fundamental difference between those two variants occurs in the acquisition costs which are 33.0% lower for variant 2 (Fig. 4b).

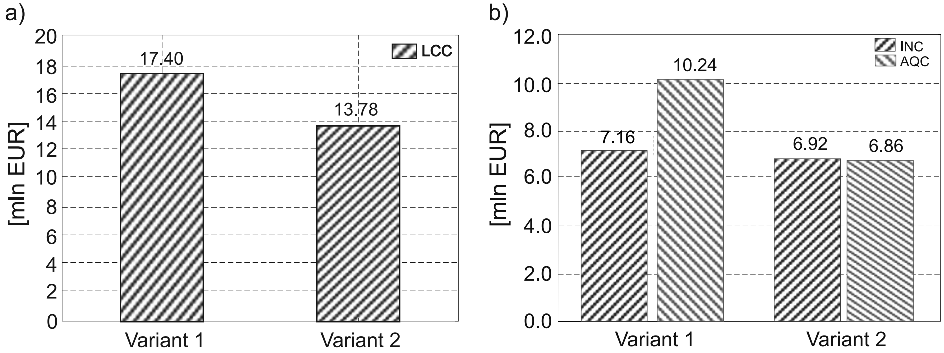

Fig. 4a) LCC of analyzed variants, b) Investments costs INC and acquisition costs AQC

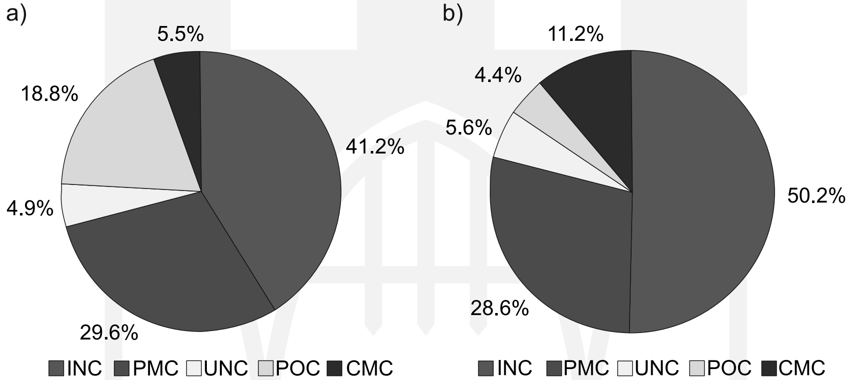

Fig. 5. Share of elementary costs categories in LCC: (a) variant 1, (b) variant 2; INC – investments cost, PMC – preventive maintenance costs, UNC – unavailability costs, POC – operation personnel costs, CMC – corrective maintenance costs

Figure 5 presents the share of basic cost categories in the LCC structure for variant 1 and 2. The main categories in variant 1 which have the biggest share in LCC are: investment costs 41.2%, preventive maintenance costs 29.6% and operation personnel costs 18.8%. The categories which have the most significant impact in variant 2 are also investment costs 50.2% and preventive maintenance costs 28.6% generated by routine repairs and overhauls of SUW 2000 bogies.

In variant 1, almost 90% of LCC is generated by handling shifting equipment at the border-crossing point (Fig. 6a). In variant 2, costs of the point 1435/1520 mm determine only 4.7% of LCC, thanks to replacing expensive in maintenance bogies exchange facilities into high availability, reliable and relatively inexpensive track gauge changing stand (Fig. 6b).

Taking into consideration the most important parameters and cost elements, there was a sensitivity analysis conducted on the identified main costs for variant 1 and 2. The analysis proved the most important factor in deciding about undertaking's efficiency, which is SUW 2000 application in transport of dangerous goods, is the price of SUW 2000 bogie with

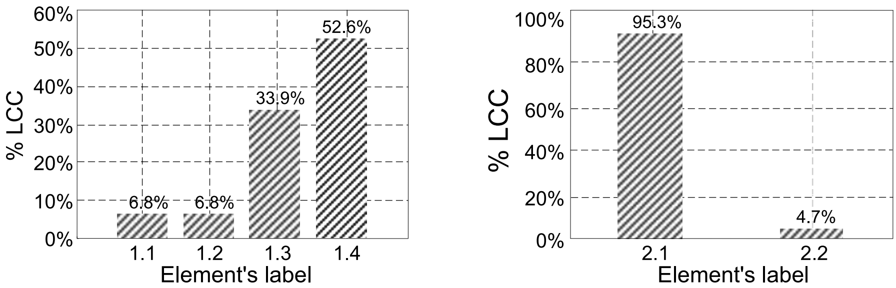

Fig. 6. LCC in system breakdown structure, a) variant 1, b) variant 2

self-adjusting wheel sets. Reducing its price by 20%, influences on lowering LCC system by 7.5% – more than 1.0 mln EUR.

Unfortunately, the current purchase price offered by the producer is very high. Therefore, the efficient distance realization of dangerous materials transport with SUW 2000 application in such conditions is limited up to 1,460.0 km.

5. Conclusions

A reliable and efficient transport system is the basis for economic development and trade between the East and the West. A major role is played by the railway transport system which offers considerable shortening of the duration of cargo transport from Asia to Europe and vice-versa. The paper presents a possibility for improving the railway transport of goods through the application of the SUW 2000 system of self-adjusted wheel sets at the border-crossing point 1435/1520 mm to replace the existing wagon bogie exchange. The comparative analysis of these two methods relied upon a decision-making model based on the LCC analysis.

The analysis demonstrated that the application of the SUW 2000 system in the transport of hazardous materials at distances of less than 1500 km is justified in technical and economic terms. The effectiveness of the project is determined by the price of the wagon bogie with self-adjusted wheel sets. The price currently on offer of EUR 86.500, is too high to ensure a return on the transport at distances of more than 1.500 km. The manufacturer should take steps to develop solutions to reduce the wagon bogie price by at least 20%. The efficiency of goods transport (including the transport of hazardous materials) with the application of the SUW 2000 system is conditioned by the wagon's turnover and the frequency of its passing through the border-crossing point 1435/1520 mm. The most efficient target area of application of the SUW 2000 system should be short-distance transports or transport where the border point with different track widths is crossed frequently during one transport process.

Narodowe Centrum Badań i Rozwoju

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