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EFFECTIVENESS EVALUATION OF RAIL EAST-WEST TRANSPORTATION SYSTEMS

Abstract

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

INTRODUCTION

Development of the European economy mainly depends on efficiency of Europe-Asia transport system which makes 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 Euro-Asian continent. Majority of the European countries, as well as 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 a train moves on the wide gauge track (1520 mm), encounter with the normal gauge (1435 mm) lines in China and Korea again. In Spain and Portugal there are even wider, 1668 mm railway tracks. (Fig. 1).

Fig. 1. Variety of the track gauge on the European-Asian continent [4].
Such differences impede the operation seriously as on the contact of railway tracks of different gauge 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.

1. INFRASTRUCTURE AT THE POINT OF THE TRACK GAUGE CHANGE 1520/1435 MM

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

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

**Fig. 2.** Techno-organizational variants of railway gauge change 1435/1520 mm [9, 12]

Generally, the transshipment technology deals with transporting cargo in the contact points of different gauge railways from the freight car of one gauge to the car of the other one. In that technology, depending on cargo kind, 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-adjusted wheel sets.

2. 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 (LCCA),

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) [14]. The structure written out in detail makes possible the LCC costs to be used as:

- a decision basis for 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) constitutes a multi-criterion decision making method called Saaty’s method as well (by the name of its 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. ANP method includes three analysis levels:

1. Level of strategic criteria, with reference to which a decision-making system is being estimated with its subsystems: profits, costs, odds and risks being considered,
2. Level of hierarchy control or criteria and sub-criteria network which checks interactions in the subsystem under investigation,
3. Network of interrelationship among the elements and its groups.

An assessment of transport systems meets the requirements of ANP method. For the subsystems of: profits, costs, odds and risks the organization, productive, technological and economical criteria are being formulated for which priority values may be estimated.

Thus, we are able to determine an optimal variant of the system or transport technology, pointing out essential profits and risks.

3. EXAMPLE OF APPLYING LCC ANALYSIS IN EFFECTIVENESS EVALUATION

As a part of the R&D projects [2, 3, 5] an effectiveness comparison of gauge change methods in the East-West system has been carried out for the following most important cargo groups:

- hazardous materials (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 effectiveness evaluation carried out.

As showed the analysis of existing state hazardous materials haulage demands to be streamlined especially. The current solutions applied in the points of gauge change in the East border of Poland (1435/1520 points) are not very effective for that kind of cargo as well as to reduce safety and ecology of haulages. 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
3.1. 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-adjusted wheel sets.

The analysis is of comparative character. Evaluation and comparison of the costs generated in the phase of selected system variant operation have 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: 274,150,0 tons/year,
- wagon load capacity: tank car of 50 tons load capacity,
- haulage distance: 1100,0 km, it corresponds to the real relations of hazardous materials between Odessa (Ukraine) Harbor and refineries on the South of Poland (for petroleum haulages) or the Mažeikiai refinery (Lithuania) and LPG Distribution Center in Poland (for liquefied gas haulages) (Fig. 3).

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

3.2. Comparison of service process in analyzed variants

LCC analysis without identification of service process in the contact points of different gauge tracks is unfeasible. In Table 1 there are presented some parameters characterizing a service process of selected variants. The parameters are obtained from a techno-organizational evaluation carried out.
**Tab. 1.** Characteristics of service process in points 1435/1520 mm for variant 1 and 2 [1, 2]

<table>
<thead>
<tr>
<th>Variant</th>
<th>Shift group [wagons]</th>
<th>Equipment of the point 1435/1520 [-]</th>
<th>Mean shifting time [min]</th>
<th>Mean time of the shift group exchange [min]</th>
<th>Number of groups per 24 hours [-]</th>
<th>Shifting capability per 24 hours [wagons]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>10 stands with elevators</td>
<td>200</td>
<td>25</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>entire number of wagons in a train</td>
<td>Gauge changing facility</td>
<td>6</td>
<td>25</td>
<td>46</td>
<td>1380</td>
</tr>
</tbody>
</table>

Taking into consideration service time and the capability resulting (Fig. 4 a) from the time, the variant 2 with self-adjusted wheel sets is unrivaled.

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 [8, 12].

![Fig. 4.](image)

*Fig. 4.* a) Shifting capability (in 1000 tons) per 24 hours, b) Percentage decrease of demand for wagons by applying SUW 2000 system depending on distance [1, 11].

Figure 4 b presents a relationship between decreasing percentage of hired wagons quantity and a haulage distance for hazardous materials. As you can interpret that graph, application of the SUW 2000 system in 1100 km long haulage relation makes achieving a 25% rolling stock saving possible in comparison with the currently applied method of bogies exchange.

Along with increasing of haulage distance, which is equivalent to decreasing of the share of track gauge barrier breaking down time in the total time of transport, the application effectiveness of the SUW 2000 system decreases.

### 3.3. System breakdown structure

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).

**Tab. 2.** Elements of structure in analyzed variants [9]

<table>
<thead>
<tr>
<th>Analyzed variant</th>
<th>Element of system structure</th>
<th>Label Applied to rolling stock</th>
<th>Label Applied to point 1435/1520</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant 1</td>
<td>1.1 Freight bogies for 1435 mm</td>
<td>1.3 Gantry crane (3 items)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2 Freight bogies for 1520 mm</td>
<td>1.4 Stand with elevators (10 items)</td>
<td></td>
</tr>
<tr>
<td>Variant 2</td>
<td>2.1 Freight bogies with self-adjusted wheel sets of SUW 2000 system</td>
<td>2.2 Track gauge changing stand of the SUW 2000 system (1 item)</td>
<td></td>
</tr>
</tbody>
</table>

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 were determined:

- 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 indicated operation information.

For variant 1, in which transport of dangerous materials is conducted at currently applied bogies exchange, operation data were gathered in the biggest point of bogies exchange, Polish freight carrier PKP Cargo S.A.. This point is situated in rail border Medyka/Mostiska (Poland/Ukraine), in III Pan-European transport corridor. Wide dependability database takes in operation range from October 2000 to May 2007.

For variant 2, dependability data were gathered as part of the economic monitored operation of SUW 2000 system, held by PKP Cargo between Poland and Lithuania from November 2000 to September 2004.

Indicated dependability parameters connected with reliability, durability, maintainability and availability constitute definition of cost elements base in LCC models.

3.4. LCC model development

Analysis has comparative character, so all categories, which are the same for both variants, have been excluded from the cost model. This assumption makes costs structure much more simple. LCC model was developed on investments and acquisition costs (1). A period of twenty-five years of operation (2008-2032) has been assumed for analysis.

\[ LCC = INC + ONC \]  

where:
INC – investments costs,
ONC – ownership costs.

Investments costs INC are sum of capital investments which are necessary for transport’s carrying out in analyzed variants of system. Ownership costs constitute both maintenance and operation costs (2).

\[ ONC = MC + OC = (PMC + CMC) + (POC + UNC) \]

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 euro (EUR) from 2008 year.

3.4.1. Investments cost (INC)

In variant 1, investments costs are determined by expenditures for renewal and modernization of infrastructure and technological equipment of bogies exchange point placed on a border crossing in Medyka (III Pan-European corridor). The aim of these investments is to enable their further operation in next 25-35 years. Estimated investments costs in system 1, covered in 2008 amounts:

\[ INC_1 = 7.16 \text{ mln EUR} \]  

Variant No 2: In 2003 there was automatic gauge changing facility installed in Medyka/Mostiska rail border. With regards to the above mentioned, purchasing costs of SUW 2000 bogies are the only investment expenditures incurred in prepared valuation. For the
analysis assumptions the number of bogies, which is required for having the carriages completed in both variants, was calculated. In variant 2 investments expenditures are incurred in 2008 and amount:

\[
INC_2 = 8,30 \text{ mln EUR}
\]  \hspace{1cm} (4)

3.4.2. Preventive Maintenance Costs (PMC)

Preventive maintenance costs of elements in analyzed variants (PMC\_i) constitute of routine repairs and overhauls expenses (5). They include labour costs (PMCL\_i) as well as costs of materials and spare parts (PMCM\_i). In order to calculate preventive maintenance costs it was essential to estimate average maintenance man-hours and materials consumption in repairs and overhauls.

\[
PMC_i = PMCL_i + PMCM_i = NPMA_i \times (MPHi \times CPH) + CM_i
\]  \hspace{1cm} (5)

where:

NPMA\_i – number of preventive maintenance action in maintenance interval of i-element,
MPHi – mean maintenance man-hours per preventive operation of i-element,
CPH – cost per hour,
CM\_i – average material cost in preventive operation of i-element.

For example, in variant 2, preventive maintenance cost of SUW 2000 bogie in maintenance cycle (between two general overhauls) amounts:

\[
PMC_{21} = 15 \times [ (30,0 \times 6,2) + 63,5 ] + 1 \times [ (115,3 \times 6,2) + 648,6 ] = 5106,0 \text{ EUR/cycle}
\]  \hspace{1cm} (6)

In variant 2, within preventive maintenance, durability of the most crucial elements of SUW 2000 bogie and track gauge changing stand were taken into account:

- maintenance-free cylindrical plain bushes (INA) in the self-adjusted wheel sets are exchanged every 400 000 kilometers,
- unlocking rails of the track gauge changing stand are exchanged after 40 000 shifting.

3.4.3. Corrective maintenance costs (CMC)

Corrective maintenance costs of i-element (CMC\_i) expressed by (7), are connected with failures appeared during operation. The base for number of failures determination, thus running repairs, was average failure intensity z_{i(t)} in each element’s maintenance interval or cycle. Failure intensity was defined within RAM analysis.

\[
CMC_i = CMCP_i + CMCM_i = H_{i(t)} \times (MTTR_i \times P_i \times CPH) + ACM_i
\]  \hspace{1cm} (7)

where:

t_i – maintenance interval of i-element [h],
H_{i(t)} – renewal function of i-element in maintenance interval [failure/h],
MTTR_i – mean time to restore of i-element [h],
P_i – personnel required for maintenance,
ACM_i – average material cost [EUR/action].

For example, in variant 2, corrective maintenance cost of SUW 2000 bogie in maintenance cycle amounts:

\[
CMC_{21} = 2,8097 \times [ (3,1 \times 2 \times 6,2) + 58,8 ] = 557,2 \text{ EUR/cycle}
\]  \hspace{1cm} (8)

In variant 2 corrective maintenance costs are connected only with failures of SUW 2000 bogie. Many years SUW 2000 operation monitoring proved that, thanks to its simple construction, the track gauge changing stand characterizes very high reliability.

3.4.4. Operation personnel costs (POC)

Operation personnel costs (9) are determined by personnel wages of bogies exchange point in variant 1 and track gauge changing stand in variant 2. According to assumptions of analysis, required number of personnel (PO_i) does not take into account persons who are the
same in both variants, for example workers of running repairs workshop, etc. Monthly wage of operating worker (MPC) equals to average Polish wage and salary in 2007: MPC = 681 EUR/month. This assumption was made in both variants.

\[ CO_1 = 12 \times (PO_1 \times MPC_1) \] (9)

In variant 1, personnel of bogies exchange point consist of 16 workers and yearly operation personnel costs amounts:

\[ CO_1 = 12 \times (16 \times 681,0) = 1307520 \text{ EUR/year} \] (10)

In variant 2, track gauge changing stand is operated by 3 workers and yearly operation personnel costs amounts:

\[ CO_2 = 12 \times (3 \times 681,0) = 24516,0 \text{ EUR/year} \] (11)

3.4.5. Unavailability Costs (UNC)

Unavailability costs (12) constitute of a sum of different kind of costs which are a consequence of non-operating system states. These costs may include: warranty costs, liability costs, opportunity costs, costs for providing an alternative service etc. System down time cost (CSD), for both variants was valuated as: CSD = 216,2 EUR.

\[ UNC_i = MADT_i \times CSD = [8760 \times (1 - A_i)] \times CSD \] (12)

In unavailability cost calculations average availability index of i-element, defined within RAM analysis, was used:

\[ A_i = \frac{MUT_i}{MUT_i + MTTR_i} \] (13)

where:
- MUT_i – mean up to time of i-element [h/year],
- MTTR_i – mean time to restore of i-element [h/year].

For example, in variant 2, unavailability cost of SUW 2000 bogie amounts:

\[ UNC_{21} = [8760 \times (1 - 0.9943)] \times 216,2 = 10795,3 \text{ EUR/year} \] (14)

Generally, LCC models of analyzed variants consist of 19 cost elements, 54 parameters and functions. Cost elements were defined in cost and system breakdown structure.

3.5. Analysis of LCC model and effectiveness evaluation

Analyses of prepared models were conducted with CATLOC software. Below, due to limited range of the paper, the most important outcomes only are presented. The calculations conducted for carrying dangerous materials in chosen transport relation of 1100,0 km presented that applying variable-gauge wheel sets SUW 2000 ensure higher effectiveness in comparison to currently used bogie exchange. LCC for variant 2, in 25 years-operation-system, is 0.82 mln EUR (4,3%) lower than in variant 1 (Fig. 5 a). Fundamental difference between those two variants occurs in operation costs (ONC) which are 37,9% lower for variant 2 (Fig. 5b).
Figure 5. a) LCC of analyzed variants, b) Investments costs INC and ownership costs ONC [9]

Figure 6 presents share of elementary costs categories in LCC structure for variant 1 and 2. The biggest share in LCC have investment costs 34,6% ÷ 57,7%. Next, in variant 1 each of unavailability and operation personnel costs constitute 30,2% share in LCC. The category which has the most significant impact for variant 2 is preventive maintenance costs – 24,9%, generated by periodic repairs and overhauls of SUW 2000 bogies costs.

In variant 1, almost 90% LCC is generated by handling-shifting equipment of point 1435/1520 mm (Fig. 7 a). In variant 2 (Fig. 7 b) costs of point 1435/1520 mm determine only 6,2% of LCC, thanks to replacing expensive in maintenance facilities of bogies exchange point into high availability, reliable and relatively cheap track gauge changing stand.

Fig. 6. Share of elementary costs categories in LCC: (a) variant 1, (b) variant 2 [9]; INC – investments cost, PMC – preventive maintenance costs, UNC – unavailability costs, POC – operation personnel costs, CMC – corrective maintenance costs

Fig. 7. LCC in system breakdown structure, a) variant 1, b) variant 2 [9]
Taking into consideration the most important parameters and costs elements, there was sensitivity analysis conducted on identified main costs for variant 1 and 2. The analysis proved the most important factor deciding about undertaking’s efficiency, which is SUW 2000 application in transport of dangerous materials, is the price of SUW 2000 bogie with self-adjusted wheel sets. Reducing its price by 10% influences on lowering LCC system by 5.8% (1.06 mln EUR).

Unfortunately, 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 1460.0 km.

CONCLUSIONS

Reliable and efficient transportation system is crucial for the economic development and trade exchange in East-West relations. Rail system which ensures shortening transport time between Asia and Europe is crucial for effective transportation system. For effectiveness assessment selected variants LCC analysis was applied as a method which allows evaluating comprehensively all phases of life cycle. The conducted calculations proved usefulness of SUW 2000 system of self-adjusted wheel sets for relations with a haulage distance below 1500 km. Analyzed example applied to the West parts of railway infrastructure 1435/1520 mm but there is also possibility of application for the East parts – China/Korea/Russia.

OCENA EFEKTYWNOŚCI KOLEJOWYCH SYSTEMÓW TRANSPORTOWYCH WSCHÓD-ZACHÓD

Streszczenie


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