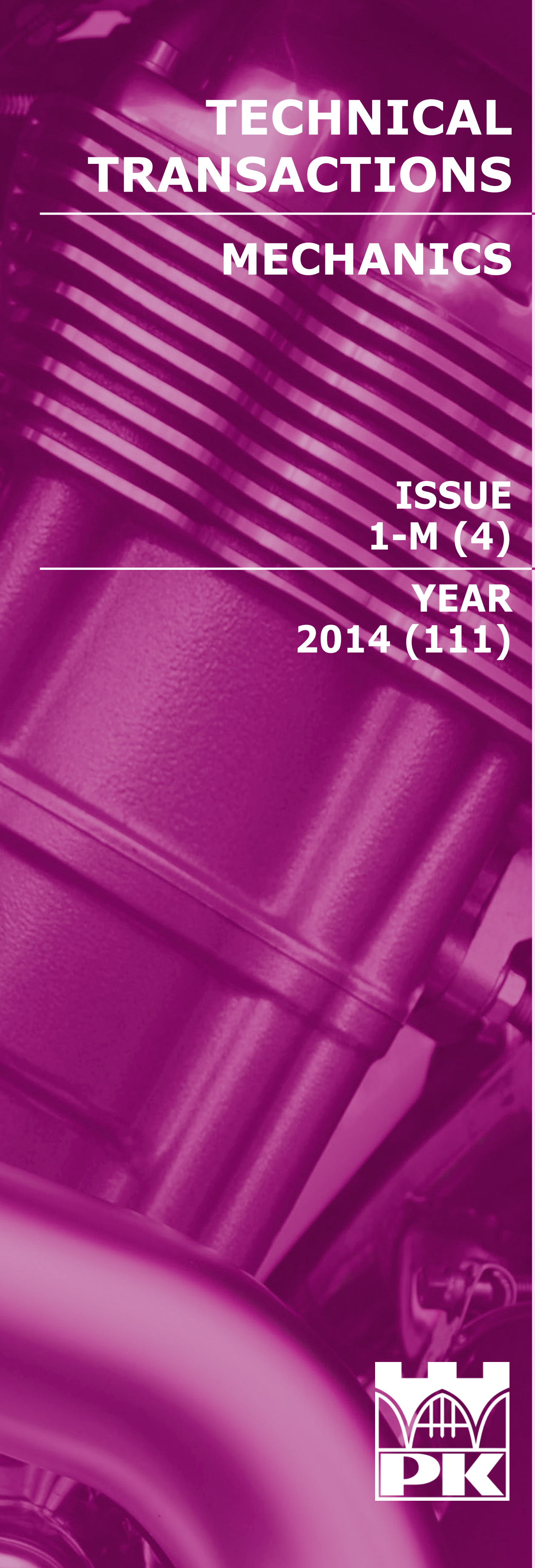

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PIOTR BERA*, MAŁGORZATA HEINRICH*, GRAŻYNA JASICA*, JAN SZYBKA*

DEVELOPING THE OPERATIONAL RELIABITY OF MOTOR VEHICLES

KSZTAŁTOWANIE NIEZAWODNOŚCI EKSPLOATACYJNEJ POJAZDÓW MECHANICZNYCH

A b s t r a c t

This article presents a process of developing operational reliability based on damage occurring during operation. A programme operating on the basis of the artificial neural network method was used to determine the probability of damage to selected engine elements. The results calculated in this way may serve as feedback information for the design process, enabling continuous improvement in the quality of the product, i.e. the automobile combustion engine. Factors taken into consideration during artificial neural network construction, the number of inputs and outputs resulting from the number of variables, and the learning algorithm were described.

Keywords: *developing reliability*, *operational reliability*, *artificial neural networks*

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

W artykule przedstawiono proces kształtowania niezawodności eksploatacyjnej pojazdów w oparciu o występujące w procesie eksploatacji uszkodzenia. Do wyznaczania prawdopodobieństwa uszkodzeń wybranych elementów silnika wykorzystano program oparty na metodzie sztucznych sieci neuronowych. Obliczane przez niego wyniki mogą służyć jako informacja zwrotna dla procesu projektowania, dzięki czemu możliwe jest stałe podnoszenie jakości produktu, jakim jest samochodowy silnik spalinowy. Opisano czynniki uwzględnione na etapie budowy sztucznej sieci neuronowej, tj. liczba wejść i wyjść wynikające z liczby zmiennych oraz algorytm uczenia.

Słowa kluczowe: *kształtowanie niezawodności*, *niezawodność eksploatacyjna*, *sztuczne sieci neuronowe*

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Designations

ANN – Artificial Neural Network
ECU – Engine Control Unit
MIL – Malfunction Indicator Light
SI – Spark Ignition
OBD – On-Board Diagnostics

1. Introduction

One method of advertising cars used by manufacturers to encourage customers to buy their products is to promote their high reliability. The word 'reliable' evokes universal trust, so that the buyer is certain that the vehicle will not malfunction frequently during operation. From the perspective of manufacturers, this assessment is most often qualitative, which is not to say, however, that they do not commission studies and analyses on the subject. A manufacturer can collect and accumulate a great deal of information on the malfunctions and defects of vehicles from their introduction on the market to their use. Warranty repairs and servicing by authorised stations and repair workshops are an excellent source of data. Analysis of damage from a design and construction point of view and identification of the characteristics of reliability enables designers to modernise vehicles and to adapt them in terms of forecasted customer demand [1, 2, 7].

The problem of the flow and application of information between the design stage and stage of use is presented below. The novel element in this work is the proposal for damage prediction through the application of neural networks. This has been presented through a hypothetical example, illustrating the possibility of applying neural networks to the assessment of the operational reliability of vehicles.

2. The process of developing reliability during the stages of design, production, and use

The development of vehicle reliability is inextricably linked to the problems of safety, operational sustainability, and environmental protection. Therefore, strict requirements relating to these problems must be taken into account during the design process. Operational databases, among other things, are sources of information for vehicle designers. They make it possible to establish and adjust repairs and preventive strategies (e.g. instruction manuals and periodical inspections). Operational data is the basis for optimisation, modernisation, and all kinds of improvements implemented through technical, technological, economical, or educational activities, as shown in Fig. 1 [2, 7].

Operational information should enable automotive concerns to make decisions regarding modernisations implemented in design solutions, methods of production, and operational guidelines introduced in new car models. Such changes, once implemented, should guarantee improved reliability and safety, ecology, driving comfort and should also account for the vehicle's serviceability and, in particular, its diagnosability. Information on damage and the subjective opinions of users are essential for the designer and manufacturer.

The identification of damage sustained during car operation makes it possible to determine probabilistic reliability characteristics that are used to plan a series of preventive measures to limit failure frequency. Information about damage resulting from production is used to improve the production process and to improve the production quality of spare parts in terms of quantity and variety. The application of modern materials and technologies providing lightness of construction enables, among other things, reduced operational fuel consumption, improved dynamic and traction properties, and the elimination of corrosion-related problems.

One visible effect of these activities is the improved reliability of vehicle parts subjected to modification in successive production lots. In turn, the implementation, for example, of a powertrain designed from the ground up, starts the process of accumulating operational information and is linked to the necessity of keeping damage statistics and of implementing improvements in those parts and components tending to fail more frequently, until the appropriate level of reliability is attained.

With regard to the introduction of the Euro III exhaust emissions standard in 2000, all cars sold in the territory of the EU are equipped with an OBD, the function of which is to monitor systems responsible for emissions of harmful substances in exhaust fumes. When emissions are exceeded by over 50%, the driver is informed by an appropriate message [8].

However, damage to some components is often so insignificant (and does not cause an increase in emissions over 50%) that it remains unnoticed or is ignored by the user. This can be termed a state of partial unserviceability. Further operation in such a state may not only

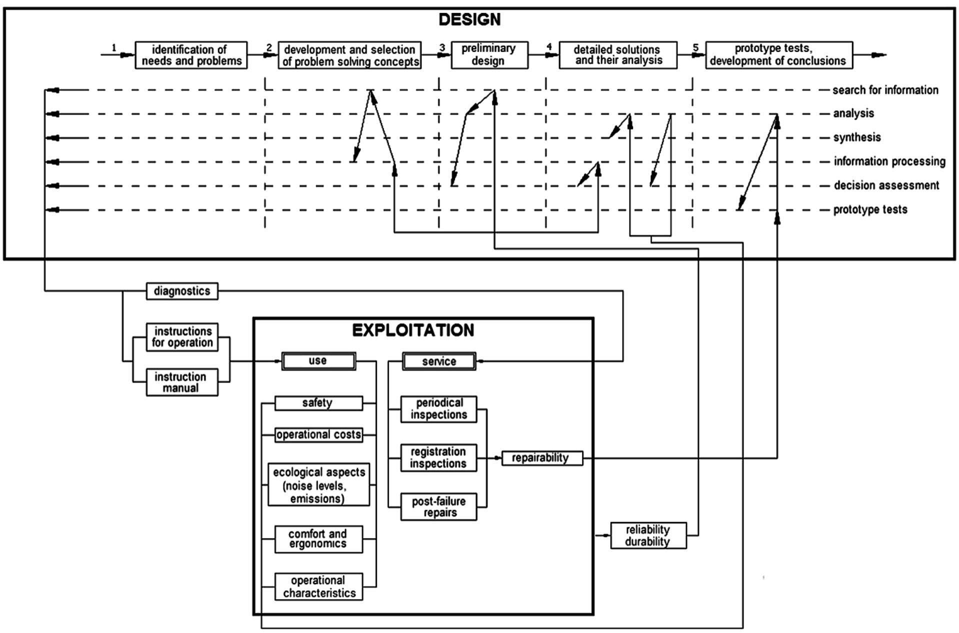

Fig. 1. Informational structure between the design and operation of a motor vehicle

cause an increase in emissions of harmful substances in exhaust fumes but can also be related to more serious damage, causing the engine to be completely unserviceable in the future and leading in turn to significant vehicle repair costs. This is why it is so important to detect and repair any damage as quickly as possible. Diagnostic testers enabling fast detection of damage based on information recorded in the ECU as so-called ‘freeze frames’, in which engine operating parameters at the time of failure are saved, play an important role in this process and facilitate the localisation of the failure [2, 8].

The illustration in Fig. 1 shows the design stages at which, and purposes for which (design function), operational information is used, as well as at which of these stages determinations concerning operation are made (operating instructions, instruction manuals, preventive procedures). It should be noted that operational information from the same group (e.g. reliability and durability indices) may be used several times in order to adjust the project as it is developed in more detail. Some of the most important qualities related to vehicle operation include safety, operating costs (fuel consumption), ecological aspects (noise level, emissions), aesthetics, comfort, and ergonomics. User requirements in this area are paramount in the design and modernisation of vehicles. Periodical inspections, registration inspections, and post-failure repairs are distinguished in the servicing subsystem. Operational data in this area makes it possible to fine-tune rational repair strategies.

Correctly established schedules of service activities and post-failure repairs constitute the principal elements of developing the operational reliability of a vehicle.

3. Determination of the probability of damage through selected elements of a combustion engine using an artificial neural network

A combustion engine is a complex technical object with a mixed reliability structure. When it reaches the customer, it is assumed to have a certain quality and related reliability. Early detection of damaged engine components and fittings makes it possible to limit an engine’s destructive influence on other units, which leads to the improvement of engine reliability as a whole over the long term.

The purpose of applying the method of ANN [3–6] for damage detection based on various types of symptoms is to restore the engine to a state of full serviceability and to improve reliability during its further operation.

Based on information concerning damage contained in the databases of authorised vehicle service stations, a program using the ANN method can be developed to calculate the probability of damage being sustained by selected engine parts based on symptoms reported by the customer and error messages saved in the on-board computer. It can indicate the location of the malfunction in conditions where knowledge about the failure is incomplete.

At the same time, results obtained by the described method may be used as feedback for designers who program an engine’s reliability during the design stage by implementing specific changes in its construction. This method may be particularly helpful in cases where the error code is not saved in the controller, and the failure is signalled only by subjective symptoms reported by the user or detected during a road test.

The following factors were accepted as malfunction criteria in the presented programme:
– the MIL lamp is lit,
– problems with starting the engine,
– starting the engine is impossible,
– uneven operation in neutral gear,
– uneven operation when load is increased,
– loss of power or stalling,
– limited engine power,
– increased fuel consumption.

Based on the symptoms listed above, the probability of damage being sustained by the following engine parts/subassemblies is calculated (with consideration of the power and exhaust system):
– engine temperature sensor,
– electric fuel pump,
– electronic throttle valve,
– ignition coil,
– spark plugs,
– oxygen sensor.

The ANN (Fig. 2) must be trained with a data set pertaining to one specific power train of a selected manufacturer from a specific production period. In the described case, the analysis concerns the SI combustion engine used in vehicles of a well-known brand that is achieving very good sales results in Poland. Thanks to the large number of vehicles of this brand serviced at authorised service stations, it is possible to collect an appropriately large data set that enables effective learning for the ANN [3]. Based on the electronic data archiving system used by service stations, information on damage symptoms and effective repairs can be obtained. In the described case, a set consisting of 100 data batches was created: *symptoms – damage*. Selected examples of damage are given in Table 1 and 2.

Table 1

Symptoms registered by the user (selected data from the training set)

	Variable / measurement number	1	2	3	4	5	…	100
1	The engine MIL lamp is lit				x			
2	Problems with starting the engine	x						x
3	The engine cannot be started							
4	Uneven operation in idle gear	x	x					
5	Uneven operation when load is increased	x		x	x			x
6	Loss of power or stalling					x		x
7	Limited engine power							
8	Increased fuel consumption						x	

Table 2

Damage to engine elements corresponding to the symptoms from table 1

	Variable / measurement number	1	2	3	4	5	…	100
1	Engine temperature sensor							
2	Electric fuel pump	x				x		
3	Electronic throttle valve		x					
4	Ignition coil				x			
5	Spark plugs			x				x
6	Oxygen sensor						x	

In the described case, the user interface of the program is of particular significance (for the mechanic performing repairs as well), so it was assumed that the user will respond to questions concerning symptoms. It was assumed that one of three answers is given to a question about symptoms: *yes*, *no*, or *partially*, which correspond to the following values of network inputs: 1, 0, 0.5. In turn, the result is given as the probability of damage of each element in the selected group (values in the range of (0; 1)).

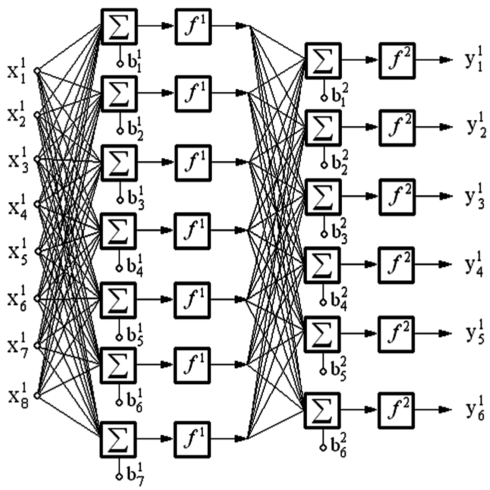

Fig. 2. Structure of the ANN used to calculate the probability of damage of engine parts

A learning set consisting of 100 data batches was used to train the ANN. During the learning process, the network learns real-life cases and approximates this data, thanks to which it can calculate the probability of damage to elements for symptoms that were not previously registered and that may arise during future operation. The minimisation of error in the learning process is a measure of its efficiency and makes it possible to state whether data approximation is proceeding correctly. The learning process is considered complete when the mean square error is not reduced in over a dozen successive learning steps (Fig. 3).

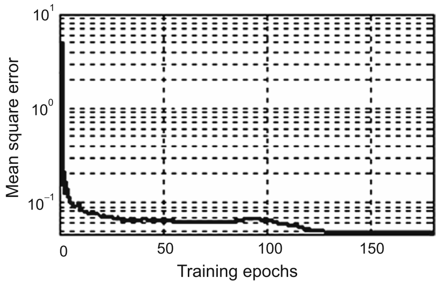

Fig. 3. Graph of the mean square error during the training process

When the learning process is complete, weights have constant values and the network can be simulated by any input parameter values.

4. Evaluation and shaping of operational reliability

Identification of a damaged part based on the diagnostic program using the ANN method makes it possible to locate damage, making it possible to perform quick repairs to restore vehicle serviceability. Data obtained during performed repairs may constitute feedback for possible design changes in the scope of production and operation (Fig. 4).

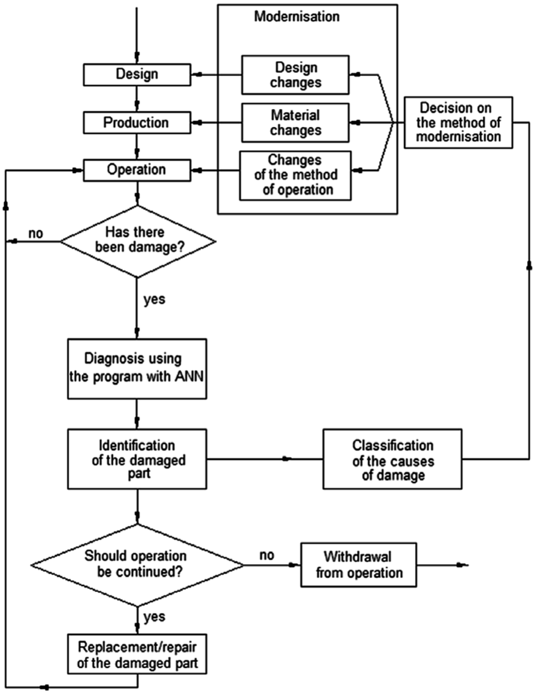

Fig. 4. The role of the diagnostic programme based on ANN in the modernisation of engine design

On one hand, this method enables fast detection and repair of current damage, thanks to which more serious malfunctions during further operation are prevented, and on the other hand, it provides feedback for the processes of design, production, and operation (Fig. 4), which leads to improvement of reliability parameters in successive modernised production series of a given powertrain.

5. Conclusions

Manufacturers aim at producing appropriately reliable vehicles, among other goals. Vehicles should not be subject to frequent failures during the warranty period, or as long as the design and technological solutions fulfil ecological requirements and safety standards. Following the operating period planned by the manufacturer, the vehicle should be withdrawn from operation. One effective method of forcing users to replace a vehicle with a new one is the uneconomical nature of further use caused by more frequent failures, combined with a customer-friendly price policy employed by manufacturers regarding exchanges and sales of new vehicles. Such a policy guarantees a continuity of vehicle sales and production that satisfies the automotive industry.

The implementation of such a policy is possible if operational studies of vehicles and the assessment of their operational reliability is conducted in accordance with the procedures and standards established by specialists concerned with the reliability of technical devices.

In this area, this work constitutes a contribution to the development of the analysed subject matter.

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JOANNA FABIŚ-DOMAGAŁA*

FMEA ANALYSIS OF POTENTIAL FAILURES OF TURBOCHARGERS FOR COMBUSTION ENGINES BY THE USE OF THE SIMULARITY METHOD

ANALIZA FMEA POTENCJALNYCH WAD TURBOSPRĘŻARKI SILNIKÓW SPALINOWYCH METODĄ PODOBIEŃSTWA

A b s t r a c t

This paper presents an FMEA analysis of turbochargers for combustion engines by the use of the similarity method and dependency diagrams. Typical functions of selected components of turbochargers were defined and the dependency between them identified. Potential failures that may appear during operation have also been defined. Using the principle of similarity, potential failures have been defined and classified.

Keywords: *FMEA*, *analysis*, *failure*, *turbocharge*

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

W artykule zaprezentowano analizę przyczyn i skutków powstawania potencjalnych wad (FMEA) dla turbosprężarki silnika spalinowego, stosując diagramy zależności oraz metodę podobieństwa macierzy. Dla wyróżnionych elementów turbosprężarki określono ich funkcje, zidentyfikowano zależności zachodzące pomiędzy współdziałającymi elementami oraz ich potencjalne wady. Korzystając z zasady podobieństwa macierzy dokonano pogrupowania i klasyfikacji potencjalnych wad.

Słowa kluczowe: *MEA*, *analiza*, *wada*, *turbosprężarka*

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List of symbols

c – component of turbocharge
e – function of component
f – potential failure
EC – dependency diagram function – component
CF – dependency diagram component – failure
EF – dependency diagram function – failure
$\mathbf{CF}^{\mathbf{T}}$ – transposed matrix component – failure
$\boldsymbol{\lambda}_{\mathbf{FF}}$ – similarity matrix failure – failure

1. Introduction

Modern passenger cars are more and more often equipped with devices to increase engine power such as turbochargers, the task of which is to delivery additional air into the combustion chamber. Turbochargers were primarily used in diesel engines. The new trend called "downsizing" spread their use to also within in small gasoline engines. Turbochargers do not consume engine power because they are driven by the exhaust gas energy, on the other hand, they are exposed to very high temperatures. Therefore the proper use of a car with a turbocharger is extremely important. Inappropriate use leads to various types of damage. Turbocharger failure usually makes the engine unable to run. Hence, there is a need to look for methods of diagnosing failures and their causes at the early stages of their formation. One of the methods that allows for the early identification of the possible failures is qualitative analysis FMEA.

The paper presents failure modes and effects analysis of failures of turbochargers for combustion engines using the similarity method in the matrix FMEA.

2. The object of analysis

The object of the analysis is the turbocharger shown in Figure 1, where: 1 – shaft; 2 – turbine wheel; 3 – compressor wheel; 4 – body; 5 – turbine housing; 6 – compressor housing; 7 – sleeve bearing; 8 – sealing ring; 9 – screw.

The analyzed turbocharger consists of a turbine and compressor connected by a common shaft. The turbine wheel is located in the exhaust system and the compressor wheel is in the intake pipe. Due to this different working conditions, they were analyzed as two separate components (despite that they are connected to each other). In the turbocharger the following components can be identified: body; turbine housing with exhaust port; compressor housing with intake port (during analysis, these components will be considered as one component – housing). In the body, there is a system of hydrodynamic bearings, however, they perform the same function, therefore only one was investigated (filters rule was adopted). The tightness of the body is provided by a sealing system in the form of two sealing rings. The analysis of the turbocharger does not include screws as despite the fact that they present, they do not cause possible failures.

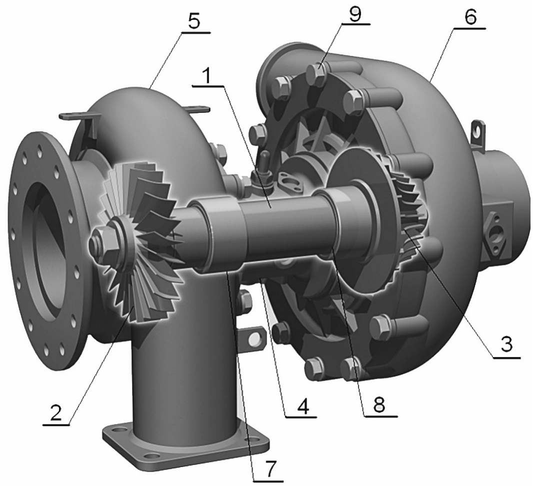

Fig. 1. Scheme of turbocharger [1]

After taking into account the above assumptions, the matrix FMEA analysis was performed for six components of the turbocharger: housing (c_1); shaft (c_2); turbine wheel (c_3); compressor wheel (c_4); sleeve bearing (c_5); sealing ring (c_6).

3. Matrix FMEA analysis

When using a matrix FMEA analysis, it is necessary to create two dependency diagrams **EC** (function – component) and **CF** (component – failure) [2]. Having built these two diagrams, matrix **EC** is multiplied by the matrix **CF**. The result of multiplication is a matrix **EF** (function – failure):

$$\mathbf{EC} \times \mathbf{CF} = \mathbf{EF} \tag{1}$$

Dependency diagram **EC** was created by assigning the analyzed components' functions, which perform in the turbocharger. Six functions were identified:

- fixing (e_1) – maintains the position of the axis of the shaft,
- positional (e_2) – proper layout of the turbocharger components,
- transport (e_3) – transferring rotation of the turbine wheel into compressor wheel,
- assembly (e_4) – assemblies' components,
- converting (e_5)– conversion of kinetic energy of the gas into the compressor rotation, conversion of compressor rotation into energy pressure causes the rotation of the shaft,
- protecting (e_6) – preventing oil leakage from one part to another, preventing the body against gas penetration, turbocharger seal, minimizing friction.

The relationships that occur between the analyzed components (c_j) and functions carried out by them (e_i) are shown in Table 1. For each components of matrix $e_i p_j$ there was assigned a value of 0 or 1. If a pair does not perform any function than value 0 is assigned. If the function is performed, a value 1 is assigned.

Table 1

Dependency diagram between analyzed components and their functions (EC)

		Analyzed components					
		c_1	c_2	c_3	c_4	c_5	c_6
Functions	e_1	0	0	0	0	1	0
	e_2	1	0	0	0	0	0
	e_3	0	1	0	0	0	0
	e_4	0	1	0	0	0	0
	e_5	0	0	1	1	1	0
	e_6	0	0	0	0	1	1

In the next step of the analysis, the dependency diagram **CF** was created. Based on the identified functions, five failures (f) were identified for six turbocharge components. These failures are: crack (f_1); overheating (f_2); seizure (f_3); corrosion (f_4); wear (f_5). Relationships between the analyzed components (c_i) and their potential failures (f_j) are shown in Table 2.

Table 2

Dependency diagram between components and their potential failures (CF)

		Potential failures				
		f_1	f_2	f_3	f_4	f_5
Analyzed components	c_1	1	0	1	1	0
	c_2	1	1	0	0	1
	c_3	1	1	1	0	1
	c_4	0	0	1	0	1
	c_5	1	1	1	1	1
	c_6	0	0	0	0	1

For each relationships $c_i f_j$, a value of 0 or 1 was assigned according to the following rule: possible influence of failure of the component: value = 1, no influence value = 0. As it arise from diagram CF destructive factors for individual components are as follows:

- turbocharger housing: cracking due to thermal shock, seizure, corrosion,
- shaft: crack, overheating, wear,
- turbine wheel: crack (due to metal fillings or other solids which block wheels and brake vanes), overheating, seizure and wear,
- compressor wheel: seizure and wear (caused by suction of air with dust),
- bearing: crack, seizure, overheating, corrosion, wear,
- sealing ring: wear.

At the last stage of the matrix FMEA, based on diagrams **EC** and **CF**, using the principle of a matrix multiplication **EF** diagram has been built which shows the probability of failures (f) for the analyzed elements (c) due to the functions performed in the turbocharger (s). Table 3 shows the probability of occurrence of failures on a scale of 0 to 3. A value of 0 in position ij denotes no effect and the value of 3 in position *ij* denotes the highest probability of *j*-th failure for the *i*-th function.

Table 3

Diagram of dependency of function – potential failure (EF)

		Potential failure				
		f_1	f_2	f_3	f_4	f_5
Functions	e_1	1	1	1	1	1
	e_2	1	0	1	1	0
	e_3	1	1	0	0	1
	e_4	1	1	0	0	1
	e_5	2	2	3	1	3
	e_6	1	1	1	1	2

For the analyzed turbocharger, the highest probability of defect seizure (f_3) and wear (f_5) is for components realizing function "converting" (e_5). These are the turbine rotor, compressor rotor and bearing.

4. Application of similarity method in FMEA matrix analysis

By using the similarity method presented in work [2] and described by equation (2), potential failures can be classified and grouped:

$$\mathbf{CF} \times \mathbf{CF} = \boldsymbol{\lambda}_{\mathbf{FF}} \tag{2}$$

Matrix $\boldsymbol{\lambda}_{\mathbf{FF}}$ (failure – component) was obtained by multiplying the transposed matrix component – failure ($\mathbf{CF}^{\mathrm{T}}$) by the matrix component – failure (**CF**) shown in Table 2. Using equation (2), a matrix $\boldsymbol{\lambda}_{\mathbf{FF}}$ has been built. Table 4 shows a fragment of $\boldsymbol{\lambda}$ matrix.

Table 4

Similarity matrix failure – component (λ_{FF})

		Potential failures				
		f_1	f_2	f_3	f_4	f_5
Functions	f_1	4	3	3	2	3
	f_2	3	3	2	1	3
	f_3	3	2	4	2	3
	f_4	2	1	2	2	1
	f_5	3	3	3	1	5

In this matrix, both columns and rows show the potential failures. The value of the element $\boldsymbol{\lambda}_{ij}$ is the probability of failure. In the new created matrix, values $\boldsymbol{\lambda}_{ij}$ are on a scale of 1 to 5. These values for $i = j$ are the criteria for grouping potential failures into four groups:

– first group: wear (f_5),
– group two: crack (f_1), seizure (f_3),
– group three: overheating (f_2),
– group four: corrosion (f_4).

Obtained groups of failures were classified into three levels according to the following rule:

– level I deals with groups of failures that can occur the most frequently: the first group,
– level II deals with two-elements group of failure with less probability of occurrence: the second and third groups,
– level III is assigned to failures with the lowest probability of occurrence: the fourth group.

Based on classified failures, depending on the diagram function – failure (Table 3) a set of possible failures were determined that need to be analyzed at the design stage of modification of the turbocharger. For this purpose, the rule of three steps was applied. This method in details is described in [3]. In the first step, failures of the analyzed turbocharger that should always be considered at the design stage or during modification were identified. This is: wear (f_5), which belongs to level I. In the second step of analysis for the function converting (e_5), identified failures have the highest probability of occurrence according to the graph of dependencies **EF**. According to this matrix for the converting functions the highest probability of occurrence is seizure (f_3) and wear (f_5). In the third step of the analysis levels to which belong failures were identified. If this is the level I identified failure must always be considered in the design stage of a new turbocharger or during modification. If this is the level II all failures belonging to this level should be examined at the design stage of a new turbocharger or during modification, and if it is a level III identified failure needs to be considered at the design stage. Failure wear belongs to the level I and should always be considered by the designer during designing or modification. The failure seizure belongs to level II, therefore all failures belonging to this level should be examined. These failures are: crack and overheating. Analysis of turbocharger by the use of similarity method shown that for processing function exist a set of four potential failures that the designer should consider. These failures are: crack (f_1), overheating (f_2), seizure (f_3) and wear (f_5).

5. Summary

This paper presents a matrix FMEA method to determine the potential failures of turbochargers. It was proposed to classify turbocharger components as the functions performed by them (EC) and possibility of failure (CF). By using the similarity method, 'failure-failure' failures were classified and grouped by three levels of significance. The results allowed for determining the set of failures that can be helpful for designers in improving turbocharger design and for users. The calculations in the FMEA analysis were performed using Mathcad.

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EVALUATION OF EFFECT OF SURFACE QUALITY OF MACHINED RAIL WAY WHEELS ON FATIGUE STRENGTH

OCENA WPŁYWU JAKOŚCI POWIERZCHNI OBRABIANYCH KÓŁ KOLEJOWYCH NA WYTRZYMAŁOŚĆ ZMĘCZENIOWĄ

Abstract

Railway transport capacities all over the world have been growing, a phenomenon which is accompanied by the requirement to increase axle loads of freight rolling stock. Apart from new wheel designs for higher axle loads, the requirements of their safety and reliability have also been growing, since these wheels are often used in extreme climactic conditions. Cruising speeds of passenger trains been increasing, which likewise brings more stringent requirements concerning the quality and safety of the supplied railway wheels. This paper describes methods of evaluating fatigue strength of railway wheel webs and methods of evaluating the quality of machined railway wheel webs. Results of fatigue tests performed on wheels machined in a standard way are compared with wheels which have been treated by shot peening, a treatment frequently used to increase the fatigue strength of wheel webs of the railway wheelset.

Keywords: *railway wheels*, *shot peening*, *fatigue strength*, *surface layer*

Streszczenie

Możliwości transportu kolejowego rosną na całym świecie, co powoduje zwiększenie nacisku na osi towarowego taboru kolejowego. Projekty nowych kół oprócz uwzględnienia wyższych nacisków na oś, muszą również uwzględnić rosnące warunki dotyczące bezpieczeństwa i niezawodności, ponieważ takie koła często stosowane są w ekstremalnych warunkach klimatycznych. Także wzrost prędkości przelotowej pociągów niesie za sobą bardziej rygorystyczne wymagania co do bezpieczeństwa jakości dostarczanych kół kolejowych. W pracy opisane zostały metody oceny wytrzymałości zmęczeniowej kołnierzy kół kolejowych oraz metody oceny jakości obrabianych kołnierzy kół. Wyniki przeprowadzonych badań zmęczeniowych kół obrabianych w standardowy sposób porównano z kołami, które traktowane były przez śrutowanie – obróbkę często stosowaną w celu zwiększenia wytrzymałości zmęczeniowej kołnierzy kół kolejowych zestawów kołowych

Słowa kluczowe: *koła kolejowe*, *śrutowanie*, *wytrzymałość zmęczeniowa*, *warstwa powierzchniowa*

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1. Material used to produce railway wheels

In Europe, the most frequently used materials in the production of railway wheels are grades ER7 and ER8, defined in standard EN 13262 [1]. These are steels with a resultant perlite-ferrite structure. The wheel rim is usually hardened in the following process: 860°C/5h/water and 520°C/5h/air. The wheel web and wheel hub are left in a normalised state without hardening. Peripheral quenching of the wheel rim by sprinkling followed by tempering induces internal compression stresses in the rim, but in the wheel web only rather moderate tensile stresses. Table 1 shows the chemical compositions of these steels, with maximum content of the various elements in percent by mass.

Table 1

Chemical compositions of steels in percent by mass, recommendedfor the production or railway wheels in Europe

Steel grade	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Cu [%]	Mo [%]	Ni [%]	V [%]	Cr+Mo+Ni [%]
ER7	0.52	0.40	0.80	0.020	0.020	0.30	0.30	0.08	0.30	0.06	0.50
ER8	0.56	0.40	0.80	0.020	0.020	0.30	0.30	0.08	0.30	0.06	0.50

Table 2 below shows basic mechanical properties which should be achieved after heat treatment applied by the wheel's manufacturer prior to mechanical machining into the final state for use. Apart from the yield point ReH , ultimate strength Rm and elongation at break A5, maintained in the wheel web must be a difference in ultimate strengths between the rim's hardened zone and the transitional zone between the rim and the wheel web, ΔRm.

Table 2

Mechanical properties of steels used in the production of railway wheels

Steel grade	Wheel rim			Wheel web		KU [J] @ + 20°C		KV [J] @ − 20°C	
	ReH [MPa]	Rm [MPa]	A5 [%]	ΔRm [MPa]	A5 [%]	Median value	Min. Value	Min. Value	Min. Value
ER7	≥ 520	820–940	≥ 14	≥ 110	≥ 16	17	12	10	7
ER8	≥ 540	860–980	≥ 13	≥ 120	≥ 16	17	12	10	5

Other frequently supplied grades are the grades defined in standard AAR M 107 [2]. These are mostly used to produce wheels supplied to American markets, where used are non--alloyed carbon steels of the chemical compositions showed in Table 3, again with a resultant ferrite-perlite structure, designated as Class B or Class C.

Unlike European standards, the AAR standard does not require basic mechanical properties to be measured, apart from HB hardness determined on the side surface of the outer face of the wheel rim, at a distance between 5 and 25 mm from the nominal diameter of the raw wheel.

Table 3

Chemical composition of steels used in railways wheels produced according to AAR standards

Steel grade	C [%]	Si [%]	Mn [%]	P max. [%]	S [%]	Cr max. [%]	Cu max. [%]	Mo max. [%]	Ni max. [%]	V max. [%]	Ti max. [%]	Al max. [%]
Class B	0.57 0.67	0.15 1.00	0.60 0.90	0.030	0.005 0.040	0.25	0.35	0.10	0.25	0.04	0.03	0.06
Class C	0.67 0.77	0.15 1.00	0.60 0.90	0.030	0.005 0.040	0.25	0.35	0.10	0.25	0.04	0.03	0.06

2. Fatigue strength tests of railway wheels

The principle of a fatigue test of railway wheels is checking whether the supplied wheels meet the parameters defined in standard EN 13 262, i.e. whether they can withstand 10 million cycles with the test level of radial stress amplitude set to 240 MPa at the critical point. Schematically, this type of test is carried out at BONATRANS GROUP a.s., preferably on the electro-hydraulic test equipment illustrated in Fig. 1.

According to this standard, the tested wheel should be loaded with such amplitude of axial force (F), cycle asymmetry parameter $R = -1$ and median value of axial force 0 N, which will induce an amplitude of radial stress ±240 MPa in the tested railway wheel with a machined wheel web, in the critical point. After the fatigue test completion, the wheel web is checked, for instance by using the wet magnetic particle inspection method, for the presence of tangential cracks developed during the fatigue strength test. If both wheels pass the test, the test is regarded as completed. However, internally, for the needs of research and design, in most cases we continue with the test using increased levels, whereby the wheel undergoes 107 cycles at each of the increased levels. The objective of the continuation with the tests until a crack develops in the wheel web, is to determine a sort of a spare strength capacity before the fatigue strength is reached, and thus being able to compare different techniques deployed to strengthen railway wheel webs.

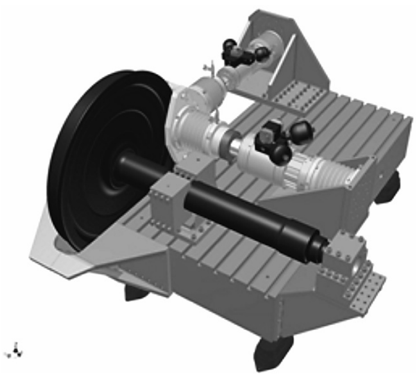

Fig. 1. A 3D model of the electro-hydraulic test equipment used for fatigue strength tests of railway wheels

Sometimes, as described in [3] for example, these tests are continued at each test level by applying only 2 million cycles to one wheel. This allows the level to be gradually increased in smaller steps, making it possible to determine the railway wheel's fatigue strength more accurately, although it must be verified on the other wheel, with the test starting at a lower level, usually reduced by two loading steps below the level at which a crack developed in the first wheel. By gradually loading the part a high number of cycles below the fatigue strength, dislocation strengthening of the material occurs, which increases the fatigue strength of the tested material.

In order to set the test correctly we must, because of the complex state of stresses, glue to the critical zone of the wheel web, identified by using a chain of strain gauges, also a 0°/45 /90° rosette strain gauge. This rosette measures stresses in a radial and tangential directions, which we need to know in order to be able to compute the actual radial test stress.

If we orient the (a) axis of the rosette strain gauge in the radial direction, the (c) axis in the tangential direction and the (b) axis under a 45° angle, the strain gauge apparatus displays, after multiplication by Young's modulus of elasticity E (206 GPa), directly stresses in each of these directions. And then, by applying the extended Hooke's Law, we determine the actual radial stress, using the following formula:

$$\sigma_{\varepsilon 2} = \frac{1}{1-\nu^2}(\sigma_a + \nu \cdot \sigma_c) \qquad (1)$$

where:

- $\sigma_{\varepsilon 2}$ – the computed radial stress [MPa],
- ν – Poisson's ratio–for the particular steel wheels and axles $\nu = 0.3$,
- σ_a – stress in radial direction,
- σ_c – stress in tangential direction.

By applying linear regression to the radial stress obtained from formula (1) as a function of the loading force, we can then determine to what value the loading force should be set in the controlling computer, so that the railway wheel is subjected during the fatigue test to a radial stress amplitude equal to ±240 MPa. If necessary, in order to obtain correct computed radial stresses, a minor adjustment in the setting due dynamic overloading is applied when carrying out a dynamic calibration at the beginning of the fatigues test.

3. Character of surface layers of railway wheels and its impact on fatigue life

Railway wheels are finally mechanically machined by turning their entire surface, either cooled with a cutting emulsion, or in a dry process without cooling. The machining is mostly done using tools with replaceable cemented carbide cutting blades of toughness class P20 and P25, sometimes with TiN and Al2O3 surface coating. The blades are mostly of a circular shape and have a 25 mm diameter, and have a suitable chip breaker. In the critical zone on the wheel's web, i.e. at the point of maximum bending moment when the wheel is stressed by imposed forces, the final wheel surface is turned in a two-chip or three-chip process, the so called roughing.

The EN 13262 standard defines for railway wheels the parameters of test stress amplitudes which the tested wheel must withstand for the duration of 10 million cycles.

For wheels supplied with their web machined, the test stress amplitude is ±240 MPa, while for unmachined wheels supplied with a raw web, the test stress is reduced by 30% to 168 MPa. This difference in fatigue strength of the final product is caused only by the coefficient of surface roughness, η_p. Generally, a smooth or polished surface increases the fatigue strength, whereas surfaces with burrs or which have been only rough-milled, lead to premature initiation of fatigue micro-cracks and ultimately to a lower fatigue strength. This coefficient of surface roughness is mainly the function of arithmetic mean surface roughness, Ra, which is determined exclusively in relation to the machining technology used:

$$\eta_p = \frac{\sigma_{cs}}{\sigma_c} \tag{2}$$

where:

- σ_c – the fatigue strength of smooth samples with polished surface and roughness Ra = max. 0.4 μm [4],
- σ_{cs} – the actual value of the fatigue strength of the structural part.

We can make a first estimate of the coefficient of surface roughness η_p by again using the diagrams in Fig. 2, used as standard in literature [4–6].

With the steel strength increasing, the coefficient of surface roughness decreases, and therefore the fatigue strength is more sensitive to changes in the surface roughness. With highly polished surfaces, we can achieve as much as a 20% increase in the fatigue strength, although we pay for this increase by higher manufacturing costs of the mechanical part. The largest reduction in the fatigue strength due to surface effects is caused by the corrosive environment which has an impact on fatigue processes by chemical reactions, both in crack initiation and in their propagation [7, 8]. Sometimes, the surface layer parameters and their impact on fatigue properties are influenced by other factors, since besides the parameter of arithmetic mean surface roughness we may include into the character of surface layers and also the impact of the quality of machining.

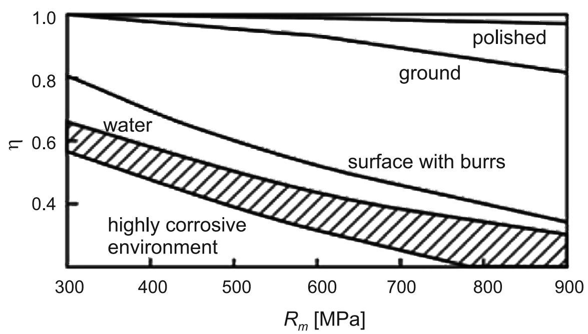

Fig. 2. Coefficient of surface roughness as a function of the strength of carbon steels [4]

Generally, it can be said that railway wheels made from grade ER7 have a sufficient spare strength capacity when testing their fatigue life. Provided the wheel is machined properly, it will withstand 107 cycles even at the amplitude level ±280–300 MPa. Wheels made from steel grades with a higher content of C (grades ER8, Class B and other), are basically even better off because of the higher strength of their normalised structure which develop in wheel web with a higher content of C. However, this at least a 16% spare strength capacity is not enough if the quality of the surface machining is substandard. If, because of tool post vibrations, or because of using a blunt cutting tool, or because of similar technological shortcomings, fissures develop in the cut surface, the fatigue strength of such products decreases rapidly. An example of such a decrease is illustrated in Fig. 3.

It has been demonstrated already in the past [9] that short fatigue cracks up to 1 mm long propagate faster than long cracks. The threshold value of the K factor to stop them is lower than the threshold value of long cracks. If we are evaluating the impact of short cracks merely by their impact on the fatigue strength, we can then conclude that short fatigue cracks up to a certain critical size, usually in the order of tens of microns, do not have any impact on the fatigue strength, while with the presence of cracks exceeding this length, the fatigue strength decreases with the increasing crack length as well as depth. These functions are illustrated in so called Kitagawa diagrams which, however, are not easily obtainable, as they require very demanding experiments to be carried out. For steel 15313.5 of the following mechanical property values: R_e = 420 MPa, R_m = 580 MPa, σ_c = 250 MPa, K_{ath} = 5 MPa·m$^{1/2}$, we managed to find in literature the diagram presented in Fig. 3. This is by annealing normalised and tempered steel of the following chemical composition ranges: C: 0.08–0.15; Mn: 0.4–0.8; Si: 0.15–0.4; P and S max 0.035; Cr: 2–2.5; Mo: 0.9–1.1; a Kitagawa diagram for this steel is presented in Fig. 10.

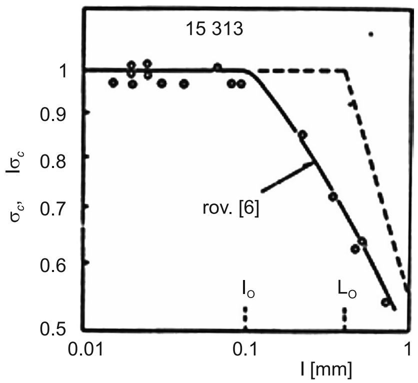

Fig. 3. Kitagawa diagram for steel 15 313.5

As can be seen from Fig. 3, a crack of a size greater than 0.1 mm will have an impact on the fatigue strength of this steel. If a crack is 0.3 mm long, the fatigue strength decreases by as much as 40%. We have observed a similar function with respect to railway wheels which had been machined on older types of vertical lathes, which left machining defects in the wheel web that we internally call fissures. Wheels with such fissures, presented in Fig. 4, did not meet the requirement of the standard on withstanding stress amplitude ±240 MPa over 107 cycles, as they failed prematurely.

Based on these results and follow-up analyses which revealed no other reason for the wheel's premature failure such as pockets of foreign material inclusions or different microstructure, etc., another experimental test programme was devised aimed at obtaining final information for evaluating the fatigue strength of wheels whose surface has been machined using different technologies.

To test the real fatigue strength of wheels machined using different technologies, flat bars as illustrated in Fig. 5 were designed. The designed shape of the test bodies allowed us to better capture the character of stresses in the given part of the wheel, and at the same time enabled us to collect such bars from the surface of a wheel with a straight or only gently sloping fixed web. The width of the test bar in the area of the fatigue failure was 24 mm, and the thickness of the sample was 12 mm.

Three variants of final surface treatment of the test samples collected from a wheel web were selected for the experiment. The wheels were machined on CNC two-slide vertical

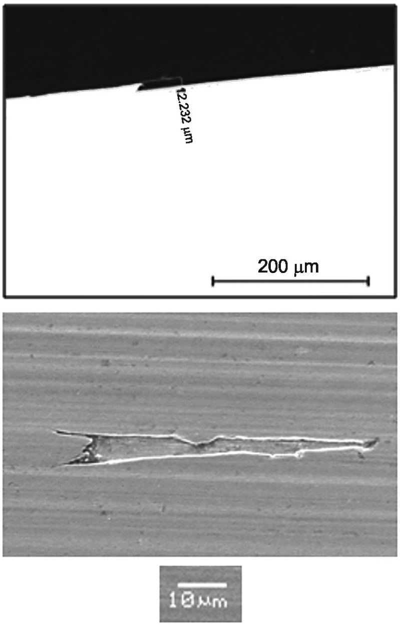

Fig. 4. View of a fissure in a wheel web groove, localised near the critical point, from which a newly developing fatigue crack starts (left), and a metallographic longitudinal section of the fissure (right)

Fig. 5. The shape of a test body for the bending fatigue strength test of different machining technologies

lathes. First, test samples were prepared in such a way that the wheel surface machined in a standard manner would be preserved. Next, samples were prepared from a place 2 mm further towards the wheel web's centre, so that both surfaces of the test sample could be ground. The surface of a third wheel was, before final machining, treated by shot peening, followed by a fine cut taken off on a lathe, and the test samples were again taken in such a way that one side traced the test body's surface.

It was expected that these samples would have an increased fatigue strength, and therefore also the reverse side of the sample and the sides were treated by shot peening to prevent the initiation of a fatigue crack in these areas. Standard material used for the production of railway truck wheels was chosen for preparing these samples, i.e. steel grade R7T and ER7.

Table 4

Surface treatment applied to the samples subjected to cyclic stressing by bending

Test bar identifier – melt, number of test bars	Surface machining technology	No. of takes – chips	Roughness after machining Ra [μm]	Cutting tool condition	Machining process with cooling	Thickness of final take	
						[mm]	[mm]
31 849.3 13	a–standard machining by turning b–grinding + turning	2	6.3–12.5 0.4	Blunt-used	NO	4	1.3
31 849.6 14	After turning strengthened by shot peening	3	3.2	New	YES	< 1	±0.5

The fatigue tests were carried out on a Schenk machine which was able to induce a bending moment of 100 kNm. The stress amplitude was induced by an adjustable crank mechanism. The induced moment was measured with a force sensor. The tests were carried out in a mode of alternating flat bending at cycle asymmetry $R = -1$ and loading frequency 50 Hz. Fatigue strength was determined using a staircase method for 50% probability of the test bar failure, for number of cycles N = 107.

Results of the fatigue strength tests of the three surface machining variants are presented in Table 5. Visual inspection of the test bars after the fatigue strength test revealed that in majority of the bars, the fatigue failure was initiated on both sides of the surface, i.e. from the machined as well as the ground surface. However, there were cases when the failure was initiated either only on the machined or only on the ground side of the surface.

These results led us to believe that the fatigue strength of a wheel with its surface machined is not much lower than the fatigue strength of those wheels whose surface was ground. Therefore, setting more stringent requirements on machining operations by specifying smaller final takes or smaller cutting tool feeds will not in the end significantly increase the wheel's fatigue strength.

Table 5

Resultant fatigue strengths of the test bodies obtained from flat bending for the three machining variants

Machining technology	Resultant fatigue strength [MPa]	Standard deviation [MPa]
Standard turning operation on a CNC dual-slidevertical lathe	268.33	9.47
Surface grinding	280.0	9.9
Shot peening of the surface before final mechanical turning	313.3	8.12

The positive effect of shot peening of the web surface manifested itself by an approximately 12% increase in the fatigue strength of the test samples. This effect can be explained not only by homogenisation of residual stresses and introduction of a compression stress component, but also by the final take during which a small tool feed was applied, with the final cut not exceeding 0.5 mm, ensuring that the strengthened sub-surface layer is not removed. Based on these results which confirmed the positive effect of surface shot peening, it was not at that stage clear which factor to what degree had an effect on the fatigue strength of those wheels which have been only machined, to the extent that some met the requirement of the standard with a sufficient spare strength capacity, while others failed prematurely.

It was only after we had analysed wheels which were machined on different types of vertical lathes that we realised the importance of this factor. A more or less identical machining technology was used on all these lathes. On some lathes, it was not possible to machine a wheel web to full satisfaction without the development of fissures. Vibrations of the lathe's slide with tool post was later identified as the main cause which, when machining a railway wheel web, leads to enormous differences in the fatigue strength of railway wheels which were machined in a standard way. When the slide rattled, fissures developed in the groove during the machining operation, which varied especially by their length. As is apparent from the Kitagawa diagrams, the longer the fissure, the lower the material's fatigue strength.

While the lathes on which, because of capacity issues, machined were wheels selected for fatigue strength tests which required two wheels of the given type, were of an older version and left fissures in the wheel web ranging in length from 150 μm do 600 μm, wheels for standard commercial contracts in batches counting hundreds of units, showed in later conducted analyses only fissures between 20 μm and 90 μm long.

An example of the differences in fatigue strength of railway wheels is presented in Table 6, in which in addition analysed on three wheels is also the effect of the cutting tool's sharpness. Therefore, an experiment was devised and conducted which studied the effect of using a new cutting tool blade, a blade which had already been used to machine four wheel surfaces or a completely blunt blade which under normal circumstances the machine operator would have to replace. Another wheel, although of a different shape, was used for comparison purposes and was machined on the above mentioned old vertical lathe.

Table 6

Comparison of stress levels of wheels machined on two different machining centres

Vertical lathe type	No. of cycles at stress level 240 MPa [×106 cycles]	No. of cycles at stress level 300 MPa [×106 cycles]	No. of cycles at stress level 360 MPa [×106 cycles]	Maximum observed fissure length [μm]
Single-slide old lathe	2.8	–	–	480
Dual-slide lathe–new cutting tool	10	10	10	42
Dual-slide lathe–slightly used cutting tool	10	10	0.5	108
Dual-slide lathe–blunt cutting tool	10	10	4.3	136

As the results of the experiment clearly show, the type of lathe used to machine the wheels selected for fatigue strength tests matters a great deal, and to a lesser degree the cutting tool blade used is also important. If we want to achieve a high quality surface, it is necessary to use a new, as yet unused blade, although the resultant fatigue strength of a wheel machined with a completely blunt tool, which is 25% better than what is required by the standard, shows that from the point of view of the product safety as well as certainty of the test result's reliability, the outcome is quite adequate.

The experiments were then extended by mapping the effect of the type of lathe used for machining the wheels. Included were the lathes upon which about 95% of all wheels at BONATRANS GROUP a.s. are machined. The results were unexpectedly good, with an average fatigue strength of the products tested and machined on these lathes being around 300 MPa.

Based on this experience, all unsatisfactory single-slide vertical lathes were discarded from wheel machining operations. Now, the standard practice is that wheels for fatigue strength tests are taken from batches machined for a client. The results of tests of the last 50 wheels show that only one type of wheel failed to meet the requirements of the EN 13262 standard. In this wheel however, which did not meet the requirements of the standard, was found a 60 μm big silicate inclusion, situated on the wheel web's surface which, as the conducted analyses showed, was the cause of a fatigue failure after 3.8 million cycles at test stress level 240 MPa. The remaining 49 wheels met the requirements of the standard with flying colours, and those wheels used to continue with the test until a crack developed, mostly failed only at a stress level of 360 MPa.

To prevent the situation from repeating itself on a different type of a lathe, a document was drafted for the needs of the Quality Control Department personnel, titled 'Guidelines for checking surfaces of wheel webs designated for fatigue strength tests', which describe how the wheel web surface is to be checked, both by visual inspection of the wheel web, and with a portable video microscope which, due to its high depth of field, is even capable of detecting fissures in the wheel web's surface of a length below150 μm.

Fig. 6. An optical video microscope used for detecting fissures in wheel webs

4. Techniques of increasing fatigue strength of railway wheels

For railway wheels, especially those destined for American markets, the requirement on increased fatigue strength of the wheel web is achieved by shot peening performed in accordance with standard AAR M107/M208,clause 7.0 [2]. The main advantages of wheels treated by shot peening are the considerably higher fatigue strength of the wheel web vis-à-vis the requirements of the EN 13262 standard, the introduction of compressive stresses into the wheel web and even distribution of residual stresses on the shot peened surface, and surface strengthening accompanied by demonstrable increase in the surface hardness.

The required effect is achieved by a stream of peening pellets blasted against a rotating solid railway wheel by two peeing units. The velocity of the stream of peening pellets and their quantity can be continuously controlled by changing the speed (revolutions) of the peening unit's motors and the quantity of the supplied peening pellets. Solid railway wheels ready for shot peening must either have already been completely finally machined, or have their web finally machined and the wheel rim with tread and the hub faces roughly machined. When shot peening a wheel rim and a wheel hub which have been only rough-machined, these surfaces do not have to be covered, as final machining will be done only after the wheel web has been shot peened. Surfaces which are not to be shot peened and have already been finally machined, must be protected against the effects of shot peening by masking them. Only after they have been shot peened can the rough-machined parts be finally machined.

From the point of view of meeting standards and ensuring stable and reproducible results for all wheels after shot peening, it is necessary to regularly check all technological parameters, such as the size of the blasted medium (pellets), the blasting intensity and the extent to which the surface is covered by the peening medium.

Controlling the size of the blasted medium (pellets) is closely related to the impact energy of the blasted pellets, and hence also to the blasting intensity. Pellets of a minimum size SAE 550 must be used for shot peening, because the pellet sorter has a sieve of 1.4 mm meshing; it is best to use pellets of size SAE 660 and grade SAE J 827. The pellet sizes must be checked at least once per shift, when the pellet magazine is being topped up with new pellets.

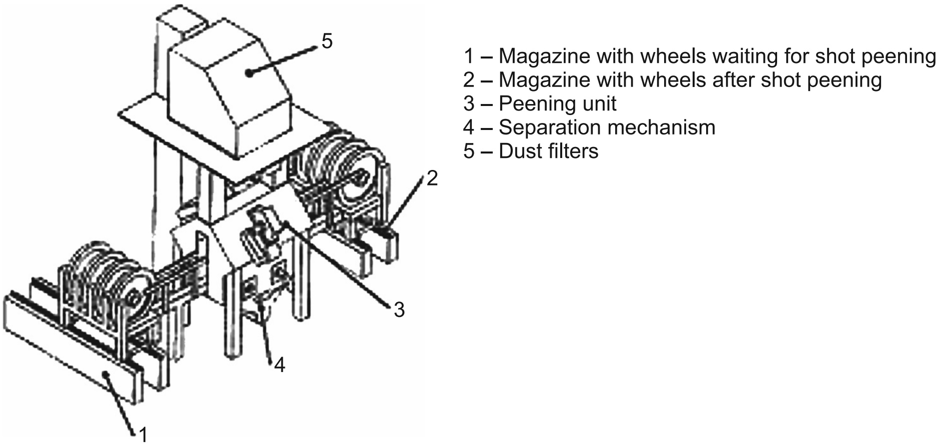

Fig. 7. A shot peening unitused to strengthen railway wheels

The blasting intensity must be sufficient to bend (sag) an ALMEN C test strip by at least 0.2 mm, and must cover 100% of the surface. At 100% coverage, the entire peened surface must be covered with mutually overlapping dents. Wheels are shot peened with an automatically selected cycle, and ALMEN C strips are measured in a special jig with a digital inclinometer. The sagging must be at least 0.2 mm but not more than 0.4 mm. A difference in the sagging of strips placed next to the wheel hub and next to the wheel rim should not be greater than 0.07 mm. The quality of coverage is checked on new, machined, as yet unshot peened wheels, at places where the strip holders are located.

The degree of surface coverage is assessed visually with a pocket microscope of 30 × magnification. The peeing time is selected so that 100% of the surface is covered. The assessment can also be done using a special fluorescent dye or an alcohol marker. When using these methods, no traces of the marker or the fluorescent dye may remain on the surface.

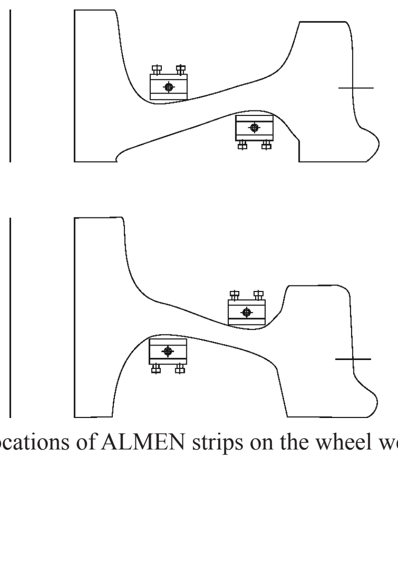

Fig. 8. Locations of ALMEN strips on the wheel web surface

In order for us to be able to qualify the effect of shot peening on the resultant fatigue strength of railway wheels on real scale, the following experiment was devised. The tests were carried out on wheel type 115.11 and 904.06. In total, four wheel variants were tested, namely a wheel with an unmachined web, a wheel with a machined web, a wheel with an unmachined but shot peened web, and a wheel with a machined and shot peened web.

The results of the tests for each of the above wheels with different machining technologies and shot peening are, for comparison purposes, presented in Fig. 9. All the tests were carried out on an Inova electro-hydraulic fatigue strength test machine at BONATRANS GROUP a.s.

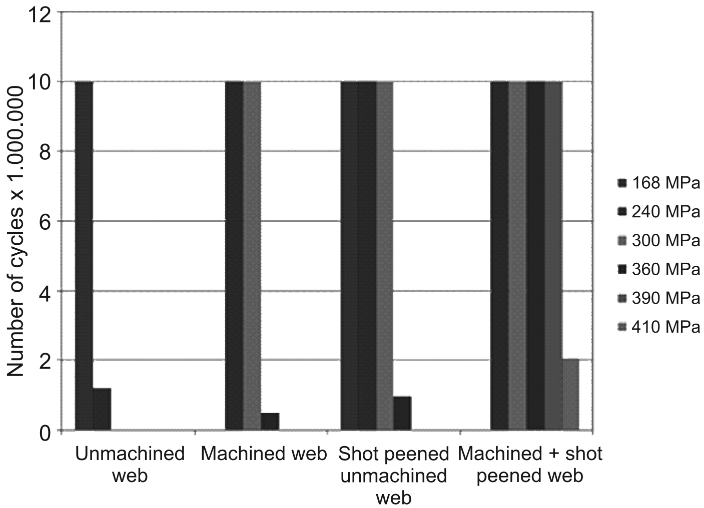

Fig. 9. Comparison of stress levels of railway wheels with different final finishing of the wheel web

As is apparent from Fig. 9, the wheel with unmachined web met the required fatigue strength of 168 MPa and failed only at radial stress level of 240 MPa. The wheel with a machined web failed only at the level of radial stress amplitude of 360 MPa.

In the wheel with the unmachined but shot peened web, the fatigue strength was increased by 78%, while for the one with the machined and shot peened web, the real increase amounted to only about 30%. The fatigue strength of the unmachined but shot peened wheel is comparable with the fatigue strength of the machined wheels.

The increase in the fatigue strength of the unmachined wheels can be explained by a decarbonised and oxidic surface layer, i.e. a poor quality surface which in addition, contains impressions whose origins can be traced to the process of forging the wheel, which can act as a stress concentrator. Shot peening, when applied to such a surface, strengthens this softer oxidised and decarbonised layer, and in addition, homogenises surface stresses and induces compression stresses which further increase the resultant fatigue strength.

5. Conclusion

The results obtained in the study of the fatigue strength of materials used in the production of railway wheelsets have led to the following conclusions:

1. When machining railway wheels, it is essential to set technology conditions in such a way that during machining, the cutting tool does not leave any minute fissures around 150 μm long, which would reduce the railway wheel's fatigue strength to such a degree that it would fail to meet the requirements of the EN 13262 standard on the fatigue life of railway wheel webs. The results obtained from the tests of railway wheels containing fissures have been confirmed by Kitagawa diagrams, which also contributed towards explaining the dramatic decrease in the fatigue strength of test samples containing cracks or fissures.
2. The fatigue strength of wheels manufactured by BONATRANS GROUP a.s. is around 300 MPa, which provides an adequate spare strength capacity when conducting fatigue strength tests at the stress amplitude level of 240 MPa required by the standard.
3. From the economy point of view, the best technique of how to increase the fatigue strength of wheel webs is to apply shot peening to the wheel's web, which is basically blasting the wheel web with steel pellets with a defined intensity determined by measuring the value of the sagging of an Almen strip, with the maximum possible coverage of the wheel web. Deploying this technique can increase the fatigue strength of machined wheels by as much as 30%, and in the case of unmachined wheels supplied with a rolled, unmachined web, by 78%.

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ELECTRIC SHOCK SAFETY IN AUTOMOTIVE ELECTRICAL SYSTEMS

BEZPIECZEŃSTWO PORAŻENIOWE W SAMOCHODOWYCH INSTALACJACH ELEKTRYCZNYCH

Abstract

The article presents the issue of electric shock safety in automotive electrical systems, discussed from two different points of view, that is the point of view of a user and the point of view of the garage personnel. The authors also review the requirements posed by the norms that are in force in this area, and discuss the problems concerning the levels of the applied and the generated voltage, which are presented with reference to typical 14 V and 28 V automotive electrical systems, 42 V systems, and the systems used in hybrid and electric cars.

Keywords: *vehicle energy demand*, *automotive electrical system voltage*, *safe vehicle operation and maintenance*

Streszczenie

W artykule przedstawiono problemy bezpieczeństwa porażeniowego w samochodowych instalacjach elektrycznych, z punktu widzenia użytkownika i stacji serwisowych. Omówiono wymagania obowiązujących norm w tym zakresie. Przedstawiono zagadnienia dotyczące poziomów stosowanych i generowanych napięć w odniesieniu do klasycznych samochodowych instalacji elektrycznych 14 i 28 V, do instalacji 42 V oraz do instalacji samochodów hybrydowych i elektrycznych.

Słowa kluczowe: *zapotrzebowanie energetyczne samochodu*, *napięcie elektryczne instalacji samochodowej*, *bezpieczna eksploatacja*

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1. Introduction

In the 20th century, the problem of electric shock safety during car operation did not exist, as automotive electrical systems were equipped with DC installations with the rated voltage of 6, 12 and 24 V (and the working voltage of 7, 14 and 28 V respectively).

The increase in the rated voltage in automotive electrical installations was a gradual process. Initially, 6 V installations were used.

In passenger cars, the increase in voltage from 6 V to 12 V took place during the 1960s, the same as in the case of lorries and busses, however in these types of vehicles, 24 V installations started to be used. The main reason for these changes was the increase in the number and the power of electricity receivers mounted in cars. While in 1970, the average demand for electricity in a passenger car did not exceed a value of 650 W, it rose up to 950 W in the year 2000 (Fig. 1). The analyses and prognoses show that the current demand may even exceed 5 kW [1–3].

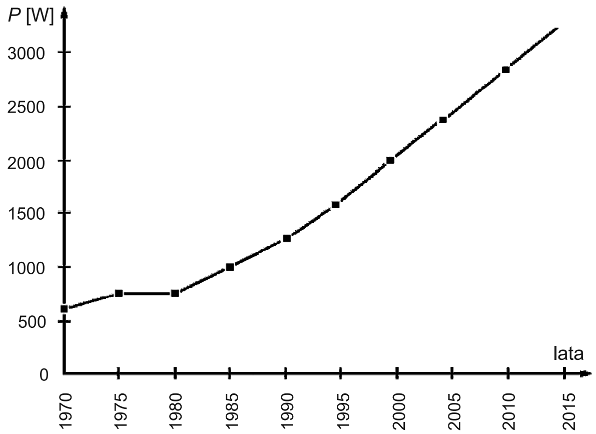

Fig. 1. The increase in the total power of receivers mounted in automotive electrical systems from 1970 onwards [3]

The increase in the rated voltage in automotive electrical systems has a number of advantages. First of all, when the power of a receiver remains at a constant level, the current intensity in individual circuits decreases, which reduces the power loss. This means that the reliability of receivers grows and the weight of automotive electrical devices, cables and wires decreases.

The transition into electrical installations of higher voltage in the automotive industry has been, and will be, a problematic issue, as there are many structural, technological and financial obstacles on its way.

The increase in the value of voltage in automotive electrical installations redefines the issues of their safe operation, maintenance and utilisation.

Polish norms concerning automotive electrical installations [7–9] do not precisely define the requirements connected with electric shock safety. Therefore, it seems fully justified to refer to general regulations concerning protection against electric shock [4, 10].

Nowadays, due to the growing popularity of hybrid and electric cars, in which the levels of the used and the generated voltage significantly exceed the values allowed, and the voltages in individual circuits differ, we found ourselves in a totally new situation.

The article presents the above issues with reference to traditional 14 V and 28 V automotive electrical installations, 42 V installations and electrical installations used in hybrid and electric cars, and concentrates on selected problems in this area.

2. 14 V and 28 V installations

Currently, the vast majority of cars are equipped with 14 V and 28 V electrical installations. In the 14 V versions, the only source of dangerous voltages are spark-ignition systems. The values of voltage generated by such engines, during regular operation, vary between 200–400 V (the primary side of the ignition coil) and 5–15 kV (the secondary side of the ignition coil). In the case of breaks in the circuits of spark plugs, the level of voltage on the secondary side of the ignition coil may reach a value of 40 kV.

Such voltage endangers human health and life. Relatively high values of internal resistance of such sources do not pose a threat to human life, though they may result in quite unpleasant sensations when the ignition circuit is not properly dealt with.

The problem became more serious when in modern engines, ignition circuits of much higher voltage started to be used (significantly greater breaks in the circuits of spark plugs) and the energies of single ignition impulses rose, decreasing internal resistance in secondary circuits of ignition coils. Because of several structural solutions (i.e. insulation) the problem of electric shock safety has so far been tackled in the above listed installations. The works [4, 10] determine border values of additional voltages (current and alternating) – Tab. 1. These are very low voltages (Extra-low Voltage – ELV).

Table 1

Border values of additional voltages [4, 10]

	Environmental conditions	Alternating current	Direct current
		[V]	[V]
1	Normal	50	120
2	Increased electric shock danger	25	60

3. 42 V installations

In 1996, a consortium of leading automotive companies was formed so that joint R&D activities concerning installations with a working voltage of 42 V (and a rated voltage of 36 V) could be undertaken.

The application of higher rated voltage in electrical installations is very advantageous, however there are a few problems concerning its installation, such as structural, technological and most of all, financial. These issues are more broadly elaborated in works [1–3].

The selection of the 42 V voltage was not accidental and was preceded with an analysis of what maximum value the voltage may rise to in an automotive electrical installation in case the voltage regulator of the alternator breaks, and the only working element that controls the value of the voltage is the car's battery. The conducted analyses showed that the maximum voltage in such a situation may amount to ca. 59 V – Fig. 2. The use of the 42 V working voltage (36 V rated voltage) in new electrical installations will fulfil the requirements presented in Tab. 1. It was assumed that the remaining problems concerning electric shock safety will be exactly the same as in the case of 14 and 28 V installations.

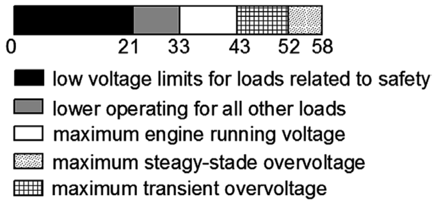

Fig. 2. Possible voltage values in 42 V installations at different stages of their work

Another argument for the change to a 42 V installation is, similar to the changes from 6 V into 12 V and 24 V installations, is a practical possibility of using existing batteries. The new voltage is three times higher than the old one, which allows for the use (at least in the period of transition) of 12 V batteries (three 12 V batteries connected in series).

The main obstacles in the way of the introduction of 42 V electrical installations are of a financial nature. Therefore, dual voltage power systems are planned to be used initially. The primary voltage will be the 42 V voltage, whereas some of the components will be powered with the 14 V (12 V) voltage from the DC/DC converter – Fig. 3.

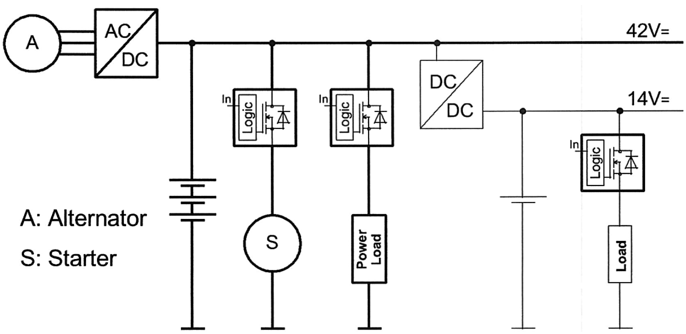

Fig. 3. The plan of the temporary 42 V installation

The last decade saw the manufacture of a few experimental passenger cars with electrical installations of the aforementioned type (i.e. Citroen Xantia).

4. Installations in hybrid cars

Hybrid cars connect the advantages of internal combustion engines with electric motors. Cars with this type of drive are equipped with a traditional internal combustion engine (either with auto-ignition or spark-ignition) and an electric motor. In a hybrid car, kinetic energy is recuperated when the speed of the moving car decreases (i.e. at the time of braking), stored in a car's battery in form of electric energy and then used by the electric motor. The way the energy is used depends on control algorithms that are dependent on the size and the voltage of the battery.

In hybrid cars, differently to traditional cars, the accumulated energy (in kWh) is referred to as a battery's capacity. This very unfortunate term (used so far only with reference to the capacity of traditional batteries expressed in amp-hours) should definitely be changed. The authors suggest that it would be much better to use the term "battery's energy capacity", or "battery set's energy capacity", as these are frequently complex and compound structures.

5. Installations in electric cars

In electric cars, a traditional internal combustion engine is replaced with an electric engine. The drive system of such a car is much simpler than that in a hybrid car. The main problem connected with the further development of electric cars is connected with the shortage of cheap, light and efficient automotive batteries, and their charging. The remaining problems are far easier to be solved. Currently, the following types of batteries can be used in hybrid and electric cars – Tab. 2.

Table 2

Types of automotive batteries possible to be used in hybrid and electric cars

	Battery type	Energy density [Wh/kg]	Remarks concerning structure
1	Nickel-hydrogen	65	Out of date technique, still used in some hybrid cars
2	Lithium-ion	170	Currently the most popular battery in electric cars
3	Lithium-air	up to 1000	Technology of tomorrow, available from 2025
4	Lithium-titanate	up to 4000	Very efficient, even in extreme temperatures. Expensive.

* Prices: in 2012 – 1 kWh – from 400 to 550 EUR; the price is to drop down to 160 EUR by 2020 (prognosis)

6. Voltage levels in automotive electrical installations in hybrid and electric cars

Voltage in 14/28/42 V electrical installations in hybrid and electric cars is very low [4], which means that these installations are Extra-low Voltage installations. In this type of installations, rated voltage that does not exceed 1000 V and direct current – 1500 V [4]. The examples of voltage values for selected car makes are presented in Tab. 3.

Table 3

Voltage levels in drive systems in selected hybrid and electric cars

	Make/model	Battery rated voltage	Type of battery	Remarks concerning engine construction
1	Lexus GS450 h	650 V	No data available	65 kM (200 kM)
2	Toyota Yaris Hybrid	144 V	Nickel-hydrogen battery, capacity of 6.5 Ah, number of cells – 120	Synchronous motor with permanent magnets, max. voltage 520 V, power 45 kW/61 kM
4	Porsche Cayenne S Hybrid	288 V	Nickel-metal-hybrid (NiMH) battery with a control system	IMG – Integrated motor. Generator by Bosch, water cooled, 34 kW (46 kM)
3	Renault Kangoo Maxi Z.E. (hybrid car)	No data available.	Lithium-ion battery, capacity of 22 kWh, weight 260 kg	Synchronous motor with a wound rotor, power: 44 kW/60 kM
5	Tesla – S model (electric car)	Charging voltage 440 V	Lithium-ion battery, capacity of 40/60/85 kWh (range of: 256/370/480 km)	270 kW (362 kM) electric motor

7. Battery charging

Electric cars' batteries are plug-in batteries that, in order to be charged, need to be plugged-in to a 230 V single phase or a 400 V three phase system. Batteries used in hybrid cars are charged directly in the car, but they can also be plugged-in to be charged, as in the case of electric cars.

8. Protection against electric shocks

Voltage levels presented in section 6 show that voltage levels in electric and hybrid cars significantly exceed the limit values of the permissible touch voltage – Tab. 1. In case car constructors do not want drivers to have access to automotive electrical installations, a new way of dealing with these installations needs to be proposed. The garage personnel should be properly trained and have suitable certificates allowing them to work with low voltage systems.

The majority of high voltage batteries that are currently used in electric and hybrid cars generate a voltage of 400 V or more. There was a law passed in the USA which prohibits car producers from using voltage higher than 60 V in their car electrical installations (5 seconds after the accident). In Europe, there are no such regulations [11].

A good example of tasks undertaken in this field is a system developed by one of the companies. The system has a sensor that can be installed in electric and hybrid cars.

At the time of collision, the sensor will immediately switch the battery off [11]. This means that the rescue team will be able to perform their duties without fear of getting an electric shock. Such solutions will have to be obligatory in all electric cars in the future.

9. Conclusions

The appearance of hybrid and electric cars caused a number of problems concerning automotive electrical installations.

Hybrid and electric cars are equipped with high voltage batteries and suitable electric generators that cooperate with them, which means that the issues of car maintenance and operation need to be approached in a totally new way.

The matter of safety in electric and hybrid cars is likely to grow in importance as cars with this type of drive will become more and more popular. However, it should be remembered that high voltage in automotive electrical installations can endanger human health and life at each stage of a car operation, breakdowns or accidents. Therefore, it will be necessary to use additional safety devices and protection against electric shocks.

The garage personnel will probably need to be properly trained and certified, as in the case of workers dealing with low voltage electrical systems.

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IMPROVEMENTS IN TRANSIENT PERFORMANCE UNDER LOCOMOTIVE DIESEL-GENERATOR MODE CHANGING CONDITIONS

POLEPSZENIE JAKOŚCI PRZEBIEGU PROCESU PRZEJŚCIA PRZY ZMIANIE WARUNKÓW PRACY ZESPOŁU SILNIK–PRĄDNICA LOKOMOTYWY SPALINOWEJ

A b s t r a c t

The algorithm of transient process control in electrohydromechanical united regulator of locomotive diesel generator and in microprocessor system of adjusting diesel crankshaft rotation frequency and power of traction generator ERChM30T is observed. The new definition of speed restrictive performance of transient process is given as well as methods of its determination and representation in microprocessor system.

Keywords: *diesel-generator of a diesel locomotive*, *quality*, *transient process*, *limiting characteristic*, *method for determination*

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

Zastosowanie elektronicznego regulatora obrotów wału korbowego i mocy prądnicy trakcyjnej ERCM30T, w miejsce elektrohydraulicznego, pozwala znacznie polepszyć jakość regulacji procesu przejścia i wyeliminować nieproduktywną dawkę paliwa. Przedstawiono metodykę określenia dopuszczalnej dawki paliwa w procesie przejścia zespołu silnik-prądnica lokomotywy spalinowej

Słowa kluczowe: *silnik–prądnica lokomotywy spalinowej*, *jakość*, *proces przejścia*, *charakterystyka graniczna, metodyka określenia*

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1. Introduction

A frequent change of power equipment mode is rather typical of diesel-locomotive operation. According to statistical observations, a change of diesel-generator speed rate occurs 50 to 60 times during each working hour during shunting and 200 to 250 times during an hour of power operation on mainline diesel locomotives. Therefore, full attention is given to the improvement in diesel-generator performance during transient (speed rate changing) processes. Accuracy and performance control of these processes is of prime importance while boosting diesel-engine by mean effective pressure [1].

2. Hydromechanical governor 4-7RS2

Hydromechanical governor 4-7RS2 developed by the holding company JSC "Kolomensky Zavod" (under the leadership of B.P. Kolosov) proves to be one of the high-water marks as far as transient process arrangement is concerned [2]. The governor high control performance is achieved through restraining fuel injection into cylinders and limiting the generator capacity in accordance with air pressure in the diesel inlet manifold. Characteristics of the fuel injection corrector and the traction generator load control (within the governor) in function of charging pressure are represented in Fig. 1.

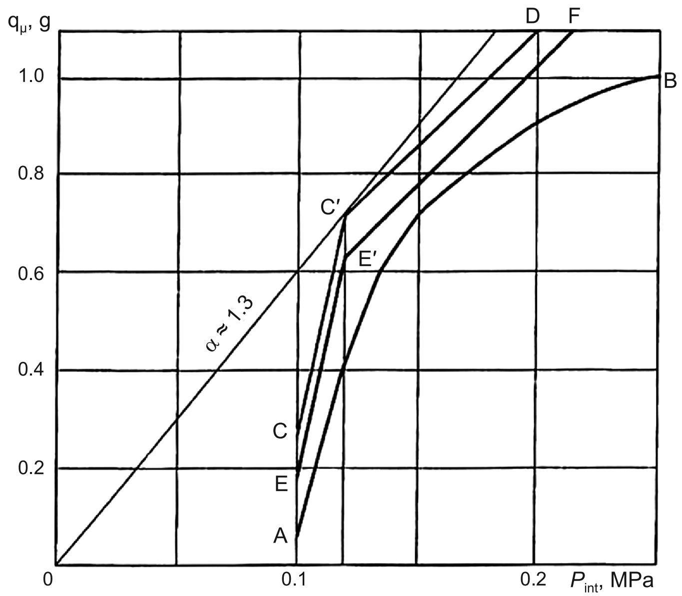

Fig. 1. Characteristics of fuel limiter and load of diesel-generator 1A- 9DG installed on diesel locomotive 2TE116 (represented schematically): AB – diesel locomotive related specified speed characteristic under steady-state conditions; CCD – limiting of fuel injection in function of charging pressure; EE'F – characteristic of power governor action aimed to reduce in diesel-generator capacity

Displacement of the locomotive handle causes mismatching between specified and actual crankshaft speeds. Therewith the speed governor draws control racks so as to increase fuel injection.

The corrector blocks off fuel injection according to the CCD curve which corresponds to preset specified value of air-to-fuel ratio (excess air factor α). Limiting of fuel injection guarantees high quality of work process in diesel engine, reduces thermal overloads of the sleeve assembly components and smoking at the exhaust. However the load produced by traction generator may turn out to be intolerably high thus making too low (or even equal to zero) the crankshaft angular acceleration necessary for mode changing. Then with satisfactory work process parameters the diesel-engine crankshaft will accelerate too slow thus increasing the transient process duration. To eliminate such possibility the corrector was modified with introduction of limiting characteristic EE'F. Provided that cyclic injection gets higher than this curve, power governor moves inductive sensor in the direction of traction generator load reduction, securing specified angular acceleration of the crankshaft (i.e. necessary rapidity of transient process).

Hydromechanical governors 4-7RS2 were mounted on diesel locomotives 2TE116, TEP70, TEM7 et al. (on diesel-engines D49). Such governor main drawbacks are instability and adjustment complexity of its characteristics under operating conditions. With further boosting of diesel-engine by mean effective pressure hydromechanical governors can't provide for adequate control accuracy and stability of diesel-engine characteristic.

3. Microprocessor control systems ERChM30T

Microprocessor control systems ERChM30T of crankshaft speed and traction generator capacity have been installed on diesel locomotives since 2000. Utilization of such a control system allows for the improvement of crankshaft speed maintenance accuracy and adjustment stability of diesel-engine and traction gear characteristics under operating conditions.

The ERChM30T governors have been installed on more than 2.000 diesel locomotives (types ChME3, TEM2, 2TE10MK, 2TE116, TEP70 etc.). The rpm maintenance accuracy amounts to ±1.0 rpm within the range 300 to 1,000 rpm. There is virtually no need for correcting the specified characteristics in operation. The microprocessor system capabilities have made possible considerable improvement in control quality and accuracy of speed characteristics of steady state modes and transient processes due to major changes in their organizational pattern. First and foremost, this concerns the method of setting transient process limiting characteristic. Previously, it was believed [1] that fuel injection limiting in the course of the transient processes is governed through specifying the value of total excess air factor (α_{Σ}). As a rule, this value was selected experimentally based on observations of diesel engine smoking at the exhaust and set at a level ranging from 1.25 to 1.30 within an accuracy of ±0.1 (not always observed). The present paper presents another approach to solving the defined problem.

4. Analysis of the indicated power variation at the transient process

Let us analyse the indicated power variation at the initial phase of the transient process. We shall assume that in the course of the transient process, a new rpm setting causes fast acting speed governor to increase fuel injection. With this process under way, crankshaft and turbocompressor rotor speeds remain constant, thus making a constant diesel engine airflow. Diesel locomotive traction generator and ancillary equipment capacities of and in--diesel engine friction power also do not suffer changes.

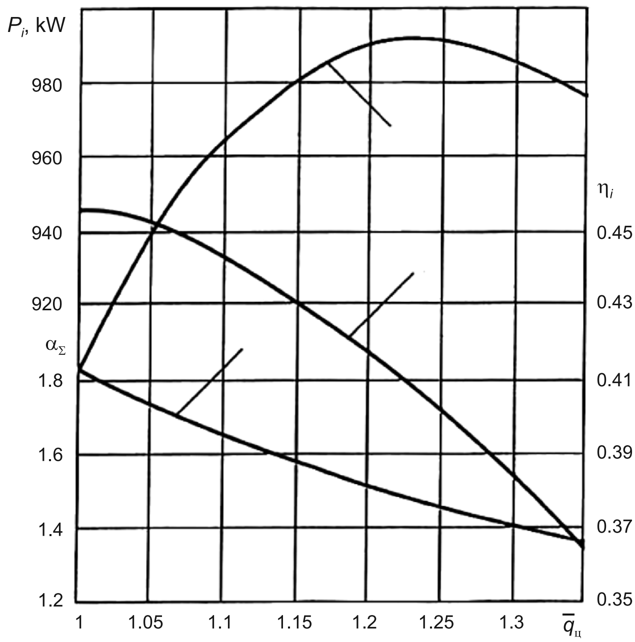

Fig. 2. On defining transient process related diesel engine speed limiting characteristic (diesel engine 12ChN26/26, crankshaft speed 64.9 rad/s (620 rpm)): $\overline{q}_F$ – relative increment of cyclic fuel injection (0.65 g/cycle is taken as a unit); α_Σ – total excess air factor; η_i – indicated efficiency; P_i – indicated power (kW)

As the cyclic fuel injection increases, the excess air factor varies in inverse proportion to it:

$$\alpha_\Sigma = \frac{G_{Vi} 2\pi\tau}{\lambda_0 q_F \omega_i Z} \tag{1}$$

where:

G_{Vi} – engine airflow (kg/s),
$q_ц$ – cyclic fuel injection (kg/cycle),
Z – number of cylinders,
λ_0 – stoichiometric relationship,

τ – engine tacticity coefficient,
ω_i – crankshaft speed, rad/s.

Considering that in respect to this process G_{Vi} = const, ω_i = const, we may write:

$$d\alpha_\Sigma = \frac{d\alpha_\Sigma}{dq_F} dq_F \tag{2}$$

where:

$$\frac{d\alpha_\Sigma}{dq_F} = -\frac{G_{Vi}}{\omega_i} q_F^{-2} \frac{2\pi\tau}{\lambda_0 Z}$$

Let us define the variation in the indicated power:

$$P_i = \frac{H_8 q_F \eta_i \omega_i Z}{2\pi\tau} \tag{3}$$

where:

$H_И$ – the lowest heat value of fuel (kJ/kg),
H_i – indicated efficiency (coefficient of performance).

With made assumptions we obtain:

$$dP_i = \frac{H_8 Z\omega_i}{2\pi\tau}(dq_F\eta_i + d\eta_i q_F) \tag{4}$$

with regard to (1) we have:

$$dP_i = \frac{H_8 Z\omega_i}{2\pi\tau}\left(dq_F\eta_i + q_F\frac{d\eta_i}{d\alpha_\Sigma}d\alpha_\Sigma\right) \tag{5}$$

or

$$dP_i = \frac{H_8 Z\omega_i}{2\pi\tau}\left(dq_F\eta_i + q_F\frac{d\eta_i d\alpha_\Sigma}{d\alpha_\Sigma dq_F}dq_F\right) \tag{6}$$

with regard to (2) we have

$$dP_i = \frac{H_8 Z\omega_i}{2\pi\tau}dq_F\left(\eta_i - \frac{G_{vi}2\pi\tau}{\lambda_0 Z\omega_i}q_F^{-1}\frac{d\eta}{da_\Sigma}\right) \tag{7}$$

In the course of the process under consideration, indicated power P_i achieves its maximum under $dP_i = 0$, i.e under:

$$\eta_i = \frac{G_{Vi}2\pi\tau}{\lambda_0 Z\omega_i}\frac{1}{q_F}\frac{d\eta_i}{d\alpha_\Sigma} \tag{8}$$

or with regard to (1) we have:

$$\eta_i = \alpha_\Sigma\frac{d\eta_i}{d\alpha_\Sigma} \tag{9}$$

Indicated efficiency value ηi, depends on α_Σ and crank-shaft speed [1].

Basing on experimental data for every specified crank-shaft speed value, we determine relationships to be stored in the microprocessor control system.

$$\eta_i = \eta_i(\alpha_\Sigma) \quad \text{and} \quad \frac{d\eta_i}{d\alpha_\Sigma} \tag{10}$$

As a case in point, Fig. 2 represents the dependencies of diesel-engine indicated efficiency η_i, total excess air factor α_Σ and indicated power P_i under crankshaft speed ω_i = 64,8 rad/s from relative increments of fuel injection. The relationships were obtained by resultant data processing of type 2TE25 locomotive diesel-engine tests carried out by JSC “Kolomensky Zavod”.

As is clear from Fig. 2, increases in fuel injection by more than 20% do not cause any increase in indicated power, thus they are fully unjustified. Herewith the excess air factor amounts to 1.5. Previously the permissible value of excess air factor was believed [1] ranging from 1.30 to 1.35. The governor 4-7RS2 limiter was specifically adjusted for such value thus allowing for injection of 10 to 15% excess fuel into cylinders. Of course this fuel combusted through-and- through, contributing to larger heat load density of structural components and more intensive smoking at the exhaust but not to increase in the indicated power.

5. Rational load control agorithm

Rather strict regulation of fuel injection increments superimposed by microprocessor system is compensated with rational load control algorithm of traction generator and correct variation of permissible injection value in terms of increasing turbocompressor rotor speed and charging pressure. In Fig. 3, an oscillograph record is represented showing the transient process of diesel-generator 2A-9DG installed on a microprocessor system equipped diesel locomotive TEP70 as for the case of drawing locomotive handle from the first to the fifteenth position.

At the transient process initial phase control racks (hp) instantaneously get on the fuel injection limiting position (hp). Microprocessor system controls traction generator current ($I_{тг}$) so as to provide for specified angular acceleration of the crankshaft (curve $\omega_д$ in Fig. 3) and near-the-limiting position of control racks $h_{p/p}$. On reaching the specified crankshaft speed (in Fig. 3 it occurs in the course of 66s), the traction generator load is regulated so as to force control racks to draw nearer to the limiting position, but not quicker than the permissible loading rate of the traction generator in tractive mode.

The represented oscillograph record demonstrates that the transient process realized in the ERChM30T microprocessor control system meets the most severe requirements of quality and accuracy of locomotive diesel-generator control. This process may be considered optimum with regard to the definition proposed in [1]. Elimination of nonproductive fuel injection according to the relationship (9) leads to an increase in fuel efficiency by 2–5%, ensures diesel-engine overloading protection and reduces hazardous emission, this is not the whole story. Fuel efficiency enhancement highest potential lies in that achieved control quality and accuracy allow for raising the level of specified (diesel locomotive) speed characteristic, thus drawing it nearer to limiting characteristic of the steady-state regime.

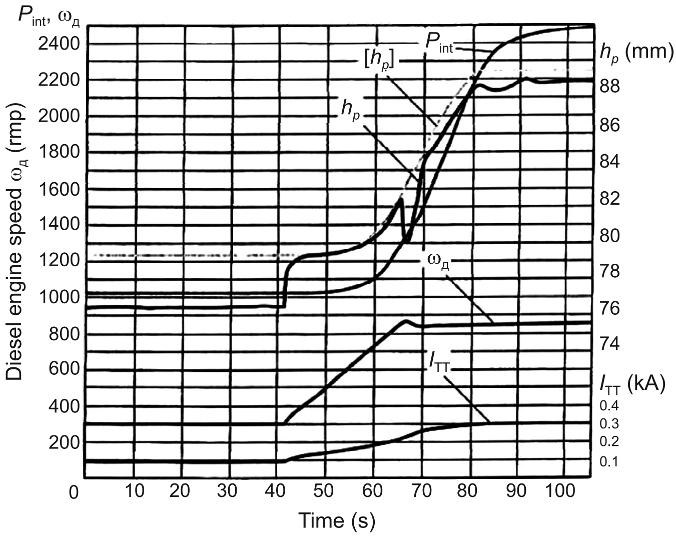

Fig. 3. Diesel engine transient process

Table 1 contains the transient process related permissible increment values of fuel injection (marked blue) depending on the indicated power level of the diesel engine 12ChN26/26 basic static characteristic at a speed of 64.9 rad/s. With high level power of the steady- state regime permissible fuel injection increment is nothing more than 10%. This implies that diesel engine crankshaft angular acceleration in the course of transient process will be low, thus contributing to an increase in the process duration. Such increment values are acceptable for mainline diesel locomotives, not affecting their productivity but contributing to an additional reduction in fuel consumption by 2–3%. Employing high-efficiency engine on shunting locomotives demands for special measures to be taken, such as the installation of a power circuit storage [3] et al.

Table 1

On defining of limiting speed characteristic as related to transient process in diesel-engine 12ChN26/26 at a speed of 64.9 rad/s

$\bar{в}_T$	B_T kg/h	α_Σ	η_i	g_i kg/kW·h	P_i kg/h	$\bar{в}_T$	B_T kg/h	α_Σ	η_i	g_i kg/kW·h	P_i kg/h	B_T kg/h	α_Σ	η_i	g_i kg/kW·h	P_i kg/h	B_T kg/h	α_Σ	η_i	g_i kg/kW·h	P_i kg/h
1,0	85,1	2,61	0,459	0,1838	463	1,0	167,1	1,82	1,456	0,185	903,2	215,9	1,65	0,44	0,191	1130	269,5	1,59	0,424	0,1987	1356
1,1	93,6	2,37	0,4595	0,1835	486	1,05	175,5	1,73	0,452	0,1865	941	227	1,57	0,425	0,1984	1144	283	1,514	0,412	0,2046	1383
1,2	102,1	2,17	0,4595	0,1835	556	1,1	183,8	1,65	0,443	0,1903	966	237,5	1,5	0,41	0,206	1153	296	1,445	0,403	0,2012	1415
1,3	110,6	2,01	0,457	0,1844	600	1,15	192,2	1,58	0,430	0,196	980,6	248,2	1,43	0,402	0,211	1177	310	1,38	0,38	0,222	1396
1,4	119,0	1,86	0,455	0,1851	643	1,2	200,5	1,52	0,417	0,202	992,6	259	1,375	0,375	0,2248	1152	323,4	1,32	0,357	0,236	1370
1,5	128,0	1,74	0,4525	0,1863	687	1,25	208,9	1,46	0,400	0,2108	991	270	1,32	0,357	0,236	1144					
1,6	136,0	1,68	0,4505	0,189	719,6	1,3	217,2	1,40	0,383	0,2203	986										
1,65	144,6	1,53	0,405	0,208	695	1,35	225	1,34	0,365	0,231	976,7										
1,7	153,0	1,45	0,365	0,2303	662																
1,75	161,7	1,37	0,34	0,248	652																

Note: B_T – fuel injection (kg/h); $\bar{в}_T$ – relative variation of fuel injection; g_i – indicated specific fuel consumption (kg/kW·h)

6. Conclusions

1. Application of microprocessor governor of crankshaft speed/traction generator capacity contributes to significant improvement of transient process control performance and eliminates nonproductive fuel injections.
2. The represented method for determination of affordable fuel injection in the course of locomotive diesel generator transient process may be used for the purpose of transient process analysis of any other dedication diesels.
3. Microprocessor control application to power equipment renders possible fuel saving at diesel locomotives of about 3–6%.

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DIRECTIONS FOR MODERNISATION AND CONSTRUCTION OF CONTEMPORARY RAIL VEHICLES

KIERUNKI MODERNIZACJI I BUDOWY WSPÓŁCZESNYCH POJAZDÓW SZYNOWYCH

A b s t r a c t

This article presents brief characteristics of rail vehicles modernised or produced by NEWAG S.A. The article discusses currently produced and modernised Electric Multiple Units (EMUs) and Diesel Multiple Units (DMUs) as well as diesel locomotives undergoing a modernisation process. Based on the presented characteristics, the rail vehicle modernisation and construction process trends prevailing in the contemporary railway market were brought closer to the reader.

Keywords: *rail vehicle*, *modernisation*, *modernisation*, *locomotive*, *Electric Multiple Unit*

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

W niniejszym artykule przedstawiono krótką charakterystykę pojazdów szynowych modernizowanych lub produkowanych w firmie NEWAG S.A. Omówiono obecnie produkowane i modernizowane elektryczne i spalinowe zespoły trakcyjne oraz modernizowane lokomotywy spalinowe. Na podstawie tej charakterystyki przybliżono trendy w modernizacji i budowie pojazdów szynowych, jakie obowiązują na współczesnym rynku kolejowym.

Słowa kluczowe: *pojazd szynowy*, *modernizacja*, *lokomotywa*, *elektryczny zespół trakcyjny*

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1. Introduction

In recent years, rail transport has been developing dynamically and new railway operators have emerged on the market. This new competitive scenario is compelling carriers to compete with one another. One of the ways of building a competitive advantage is to have modern rolling stock.

Rail vehicles used for passenger transport should be renowned for their great reliability, high levels of safety, superior comfort for passengers as well as by low operational costs. The locomotives are principally expected to consume less energy, offer better working conditions for the engine driver and to improve the traction properties of the train. Additionally, all vehicles have to comply with the requirements set forth in various items of domestic and international legislation.

NEWAG S.A. is one of the companies dealing with the modernisation of existing rolling stock and production of new units, having all of the aforementioned features.

2. Electric Multiple Units (EMUs)

For several years now, the Company has been upgrading EN57 and EN71 electric multiple units (EMUs). As a result of the first major overhaul, which comprised the replacement of rail-car bodies and traction systems, two new types of vehicles were created. These are called 14WE (Fig. 1) and 14WE-P.

From the original electric multiple unit, only the bogie frame, frame elements and bogies were kept and were subjected to a major overhaul. The retrofitted vehicles were adapted for handling suburban commuter traffic. To enhance operational comfort, the traction system was retrofitted in accordance with documentation drawn up by the 'ROLLING STOCK' Rail Vehicle Institute. The traction system consists of two bogies: 36AN rolling bogie and 23MN motor bogie. The modernisation process involved the changing of the method of springing wheel sets. The multiple plate springs and leaf springs were replaced with cone springs as well as metal and rubber springs, which improved travelling comfort to a large extent. At the same time, the wheel set driving was changed by means of the introduction of a new type of axle-boxes with bearings marked NJ + NJP 130 [1].

Fig. 1. 14WE Electric Multiple Unit (EMU)

The scope of other modernisation projects of the EN57 and EN71 electric multiple units (EMUs) comprises mainly the change of external appearance, enhancement of travelling comfort through improvement of the EMU interior and installation of equipment enabling the disabled to use the trains. An example of such a retrofitted Electric Multiple Unit (EMU) is presented in Figure 2.

Fig. 2. EN71 Electric Multiple Unit (EMU) with modernized front (Photo by G. Motyka)

The design of the engine driver's cabin was modified by making a new steel frame incorporated into the remaining part of the vehicle. To the frame, a self-supporting front made of polyester and glass laminate was added using special adhesive. At the front, the heated wrap-around window was incorporated using a special adhesive.

In the car, a toilet cubicle was added. It is suitable for use by the disabled. To this car, folding ramps were added that enable the disabled to embark and disembark from the train. Additionally, the rack system was added to enable the carrying of six bicycles in a vertical position.

In the motor car, three second class compartments were separated, divided by two vestibules. In the upgraded vehicles, the partition walls and sliding door were removed and in their place, windscreens were installed.

The engine driver's cab was modernized in the EMU. Thanks to the relocation of partition walls, the engine driver's cabin was enlarged. It is now equipped with new, ergonomic seats for the engine driver and assistant driver enabling quick evacuation.

The previously applied pneumatic windscreen wipers were replaced with electric windscreen wipers with washers. To improve visibility in harsh weather conditions, a heated windshield and new sun visor were installed.

The engine driver's console was modernized in accordance with current effective standards. In addition to standard keys and indicators the console also contains a multiprocessor, which displays operational parameters when the train is on the move. Figure 3 shows the modernized engine driver's console in EN57 and EN71 Electric Multiple Units (EMUs).

The retrofitted EN57 and EN71 Electric Multiple Units (EMUs) are equipped with internal and external surveillance systems. The internal surveillance system enables recording of events onboard the train and is performed using television cameras, the picture is displayed on two 17" monitors [2]. The external surveillance system ensures good visibility of all areas next to each side of the train, which in fact replaces the conventional mirrors.

Fig. 3. A view of the console in EN57 and EN71 Electric Multiple Units (Photo by G. Motyka)

In the retrofitted EMUs, the same bogies were installed as in the 14WE train sets. To propel EMUs, asynchronous motors were applied and thus the combined driving system was created together with a two-shift final drive.

The first Electrical Multiple Unit (EMU) built by NEWAG S.A. from scratch is 19WE (Fig. 4).

Initially, the 19WE Electric Multiple Units were designed to go to a maximum speed of 130 km/h. Now these vehicles can be operated at a speed of 160 km/h. Because of the interior layout, the EMU has been designed to handle local high density passenger traffic. The basic arrangement of the EMU is "s+d+d+s" (motor car + trailer car + trailer car + motor car). In case of high traffic density, the EMU can be operated using multiple traction. In order to perform the fast coupling of units, automatic self-acting couplers made by Voith were applied.

Fig. 4. 19WE Electric Multiple Unit (EMU)

The interior of the 19WE Electric Multiple Unit was arranged in such a way as to achieve the highest possible number of passenger seats. Therefore twin seats were installed using row and opposite layouts (2+2), otherwise the seats were installed using the "metro" layout. Thanks to such a layout, the EMU seating capacity is 183 seats and the total number of standing places is 702, assuming 5 people per m^2 and 1222 standing places assuming that per m^2 there will be 10 persons [3].

The 19WE Electric Multiple Unit has been adapted to carry the disabled. In the motor cars, a space has been designated for mounting two wheelchairs. The disabled may access the EMU using lifts or platforms, depending on the ordered version. The floor height above the rail head level is 1160 mm.

The EMU has been equipped with a multimedia system. It offers the possibility to broadcast audio-video signals throughout the train which is activated automatically. The system consists of among others, two 17” display monitors in a vandal-proof casing. The passengers’ safety is assured by an internal and external surveillance system.

To enable the EMU to drive at 160 km/h, an additional place was added for the assistant driver in the engine driver’s cabin, which consists of a second seat and an additional console. The additional console for the assistant driver comprises: a dead-man’s handle; warning horn manipulator; emergency brake; seat movement control button.

The 19WE Electric Multiple Units (EMUs) are equipped with rolling bogies of the 70RSTa type and driving bogies of 70RSNa type. These bogies comply with the safety requirements for driving with faulty springs of the second degree, with a maximum speed of 60 km/h. The bogies are equipped with a two-level springing system. The first level of springing consists of four concentric double-coil springs mounted in equalizers’ guides. The second level of springing consists of two pneumatic springs made by PHOENIX.

The second newly built Electric Multiple Unit is 35WE called “Impulse” (Fig. 5). The 35WE Electric Multiple Unit has been designed for handling high density local traffic. The train consists of six cars with the following arrangement: “s+d+s+s+d+s” (motor car + trailer car + motor car + motor car + trailer car + motor car). The 35WE Electric Multiple Unit, like the previous EMU, has been designed to travel at a maximum speed of 160 km/h. The Electric Multiple Unit has been designed to carry the disabled. The disabled wheelchair passengers may access the train through platforms mounted on both sides of terminal units.

Fig. 5. 35WE Electric Multiple Unit (EMU) (Photo by Ł. Mikołajczyk)

In the passenger area, between doors of the units there are double seats facing forward or backward with an appropriate aisle width ensuring comfortable access for passengers. In the section designed for large baggage (A and F train units), including bicycles, the seats are hinged and installed according to ‘metro’ spatial layout. In these train units, space for wheelchairs has also been designed – there are hooks for fixing wheelchairs. The floor height above rail head level in the entrance zone is 760 mm for train units equipped with a toilet cubicle, whereas for the train units without a toilet cubicle, the floor height above rail head level is 850 mm [4].

Because the EMU has been designed to run at 160 km/h, in compliance with the current legislation, the engine driver's cabin is equipped with two driver's seats. One is for the engine driver, the other one for the assistant driver. The seats have been mounted in a manner such as to allow for quick evacuation.

The 35WE Electric Multiple Units are equipped with electronic energy meter called the LE3000plus. The LE 3000plus energy meter is a modern device for settlement purposes supporting metering of the power and traction energy in the direct current (DC) Electric Multiple Units. Thanks to the built-in GSM modem, it is possible to transmit metering data remotely and automatically to the settlement systems.

The 35WE Electric Multiple Unit, similarly to the trains described above, has a built-in surveillance system to ensure a safe journey for passengers and also has a public address system to provide information for the passengers.

The 35WE Electric Multiple Unit is based on four, biaxial 70RSNd driving bogies and four, biaxial 72RSTd rolling bogies of the Jacobs type.

The 35WE Electric Multiple Unit is powered by eight asynchronous electric motors with a total power of 3200kW, coupled with axial transmissions mounted on four driving bogies.

The most modern Electric Multiple Unit produced by NEWAG S.A. is the 31WE (Fig. 6). The 31WE and 35WE Electric Multiple Units differ in the number of units, traction system and driving system.

The train consists of four units in the Bo2'2'2'Bo configuration (motor car + trailer car + trailer car + motor car).

Fig. 6. 31WE Electric Multiple Unit (EMU)

The 31WE Electric Multiple Unit is based on two, biaxial 70RSNc driving bogies and three, biaxial 72RSTc rolling bogies of Jacobs type.

The 31WE Electric Multiple Unit is powered by four asynchronous electric motors with a total power of 500 kW, coupled with DOSTO-GETRIEBE axial transmissions mounted on two driving bogies [5].

The 31WE Electric Multiple Unit has been designed to run at a maximum speed of 160 km/h. During official certification tests carried out by the Railway Engineering

Institute in February of this year, the EMU reached the speed of 211.6 km/h. The tests were carried out on a section of central trunk line, between Psary and GóraWłodowska. The in--test and after-test performance of all devices was correct.

The fittings of both EMUs and the engine driver's cabin are pretty much the same. Differences may occur due to EMU customization for specific users. Figure 7 shows samples of interior layouts of 19WE, 35WE and 31WE Electric Multiple Units. Figure 7a shows a view of the compartment with double mounted seats, whereas Figure 7b shows a train unit with a ticket machine installed, Figure 7c shows a compartment with seats mounted according to the "metro" spatial layout, whereas Figure 7d shows a compartment with seats for the disabled.

Fig. 7. Examples of interiors of Electric Multiple Units (Photo by Ł. Mikołajczyk)

3. Diesel Multiple Units (DMUs)

Some of the Diesel Multiple Units that comply with all required standards and regulations as well as the expectations of rail vehicle users are DMUs marked 220M and 221M (Fig. 8).

The major difference between the two DMUs is the different number of train units. The 220M Diesel Multiple Unit is a two-unit vehicle, whereas 221M DMU is a three-unit train. Diesel Multiple Units have been designed for passenger transport on local lines with high traffic flows, especially on non-electrified railway lines.

The basic arrangement of the 220M DMU is “s+s” (motor car + motor car), whereas for the 221M DMU – “s+d+s” (motor car + trailer car + motor car). Both DMUs, depending on operational requirements, may be operated in multiple traction mode.

In both DMUs, 74RSNa driving bogies and 72RSTa rolling bogies have been used. To power 220M DMU, the PowerPack propulsion by MTU was used. It consists of a diesel motor of type 6H1800R85L and ZF-EcoLife Rail transmission. To power 221M DMU, the PowerPack propulsion by MTU was used. It consists of a diesel motor of type 6H1800R84 and hydrodynamic transmission of type ZF [6, 7].

The two-unit DMU has two motors, one motor in each train unit, whereas in the three-unit DMU, the propulsion systems are mounted in each drive unit of the DMU.

Both DMUs may be operated at a maximum speed of 120 km/h.

Fig. 8. 220M and 221 M Diesel Multiple Unit (DMU) (Photo by Ł. Mikołajczyk, G. Motyka)

A part of the passenger compartment (Fig. 9) has been lowered, and in that part the unit has been adapted for carrying wheelchair passengers, passengers with large luggage and for carrying bicycles and skis fixed in special holders. Additionally, in the low floor car, a toilet cubicle, operated in a closed loop system, has been fitted. It has also been adapted for use by the disabled.

To enable boarding and deboarding for the disabled, the DMUs have been equipped with lifts.

Fig. 9. Passenger compartment of Diesel Multiple Units (Photo by Ł. Mikołajczyk)

The Diesel Multiple Units have been equipped with, among others, a public address system, internal and external surveillance systems, operational data recorder, passenger counting system and a public address system. To ensure the safety of people in the passenger compartment, the DMUs have been equipped with panic buttons, and also electrical sockets which will make it possible to plug in a portable computer or a mobile phone.

All DMU doors are automatically closed when the DMU exceeds the threshold speed of 5 km/h.

The engine driver's cabin has been designed with the prime intention of providing very good working conditions for the engine driver. The cabin design enables the engine driver to observe both sides of the train and allows for fast and easy evacuation. The engine driver's cabin is equipped with external mirrors, heated and adjusted from the inside with the option of folding them while the train is on the move and once the journey has been completed.

4. Diesel locomotives

NEWAG S.A. upgrades locomotives to help to comply with the prevailing current requirements in the railway market. Examples of such upgrading projects include diesel locomotives of 6Dg/B, 15D or 16D types.

The diesel locomotive of 6Dg/B type (Fig. 10) is an example of a complete upgrading of the shunting diesel locomotive SM42. The scope of upgrading included, but was not limited to: a change of the locomotive's external appearance; improvement of engine driver work ergonomics; replacement of the driving unit. The retrofitted locomotive still has the same traction system, which employs 1LN bogies.

Fig. 10. The diesel engine of 6Dg/B type

The locomotive now has a modern shape. During the modernisation process, the height of the engine rooms was reduced by approximately 300 mm (compared to the previous solution), which greatly improved visibility from the engine driver's cabin.

The working conditions of the engine driver were also improved thanks to the application of an air conditioning system. A modern KL20E air conditioning unit made by Konvekta with a cooling capacity of 4.3 kW has been installed in the locomotives. The air conditioning units use an environmentally-friendly coolant R134a. Additionally, under each console, a Zephyr 3D water heating system by Webasto was installed. The water heating system is a part of the water cycle of the diesel motor C27. In the locomotives, the installation of a mechanical tachograph with registration on paper tape was abandoned. Instead, a modern electronic tachograph TELOC 1500 by HaslerRail was installed. It registers operational parameters on digital storage cassettes (EKP).

During the modernisation process, a brand new design for the engine driver's cabin was developed (Fig. 11). The cabin width was enhanced. The side walls were equipped with modern sliding plug windows with internally bonded window panes. The windshields were also constructed using internal bonding technology, and the panes are equipped with on electric heating system with a total power of 770 W [8].

Fig. 11. Engine driver's cabin in the locomotive 6Dg/B (Photo by Ł. Mikołajczyk)

In the cabin, there are two ergonomic engine driver's consoles. To enhance the working comfort of the engine driver for each console, ergonomic seats, made by Grammer, were installed. The seats have a profiled backrest and allow for adjustment to match the anthropometric features of the engine driver (adjustment of armrest, seat height), additionally they are equipped with vibration dampers. The engine driver's seat design allows for a 180-degree turn.

The engine driver's cabin has been mounted on the frame by means of four metal and rubber elements without metallic (rigid) connections with other parts of the locomotive. This ensures the maximum reduction of vibrations transferred to the cabin structure.

The diesel engine a8c22 was replaced with a new 12-cylinder, V-engine with microprocessor controlled fuel injection, turbocharged by means of two turbochargers made by Caterpillar from C27 ACERT (DITA) series. The engines from that series meet the most stringent exhaust-gas emission standards according to EU Directive 2004/26 EC (they comply with the STAGE IIIA exhaust-gas emission standards) with the total output of 708 kW.

The driving unit consists of the aforementioned diesel engine and main synchronous generator of Ghp 400 M4C type and auxiliary synchronous generator of Ghp 315 S4K type. The main generator is connected directly with the engine crankshaft by means of a flexible shaft coupling of CM8000 type. The 6Dg/B locomotives are equipped with devices enabling a precise measurement of used fuel. The fuel consumption measurement system has been designed for monitoring, registration and transfer in real time of operational data including vehicle location and information about fuel volume in the tanks and information about fuel consumption by the locomotive's diesel engine in particular.

As a result of the modernisation of the SM48 diesel locomotive, two types of diesel locomotive were obtained: 15D and 16D (Fig. 12). The 15D locomotive has been designed for operation using regular gauge track, whereas the 16D locomotive has been designed for the operation on broad-gauge track with a gauge of 1520 mm.

The modernisation process included but was not limited to the modification of the locomotive appearance to give it a modern look, adaptation of the driver's cabin to the current prevailing standards and replacement of driving unit. The bogies were not upgraded, only necessary repairs were performed.

During the modernisation the project, the height of engine rooms was reduced, which greatly improved visibility from the engine driver's cabin.

Fig. 12. 15D/16D diesel locomotives (Photo by Ł. Mikołajczyk)

The cabin design enables the engine driver to observe each side of the train set and allows for easy and fast evacuation. The modernized consoles allow for fast and easy operation. The drivers' seats are based on a metal frame, made of bent tubes and sections and allow for fast evacuation. Additionally, the seats may be adjusted longitudinally and vertically. Additionally, to improve the working comfort for the engine driver, the seat has a mechanical system of damping vibrations felt during train running, with the selection of body weight of the seating person. The ergonomic finish of the seat is supplemented with the adjustable headrest and two adjustable folding armrests.

In the locomotives air, conditioning unit was installed in the engine driver's cabin, which uses an environment-friendly coolant R134a.

The driving unit consists of a 3512C diesel engine with the power of 1480 kW, main generator Glp 500 L4 made by EMIT S.A and auxiliary generator Ghp 315 M4K. The main generator is connected directly with the 3512C engine crankshaft by means of flexible shaft coupling. 3512C diesel engine made by Caterpillar complies with UIC exhaust gas emission standard STAGE IIIA.

The locomotive is equipped with a fuel consumption control system, which enables the determining of the location of the rail vehicle and the transferring of information about quantity of fuel left in the tanks or information about fuel consumption by the locomotive's diesel engine. The locomotives were equipped with ED118A traction engines. The ED118A traction engine has been designed to convert electric energy generated by the main generator into mechanical energy of rotary motion. The original Russian engines were subjected to a major overhaul and additionally, the engine insulation was upgraded to H class [9].

The locomotives are equipped with a surveillance system. The surveillance system allows for, among other things, the ability to watch the railway line in front of the vehicle. Additionally, it is equipped with such functionalities as live video display, search and playback of any piece of video according to date/time or event and remote surveillance of the locomotive via Internet using a personal computer (PC).

Some locomotives are also equipped with a radio control system. The components of the system are shown in Figure 13.

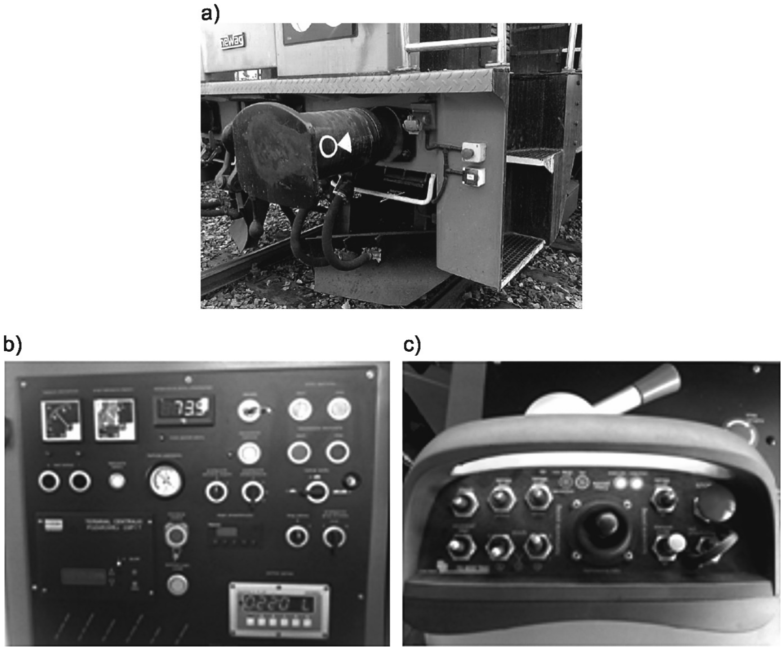

Fig. 13. Locomotive radio control system components

The locomotive control system allows for its control from the outside of the engine driver's cabin. The locomotive is equipped with emergency braking push-button (Fig. 13a), on the console there is a panel (Fig. 13b) that enables the switching of the locomotive over to radio control mode. The control is exercised using a joystick (Fig. 13c).

5. Closing Remarks

Based on brief characteristics of the presented vehicles, produced by NEWAG S.A., it can be remarked that the directions of modernisation and construction of rail vehicles include mainly the change of vehicle appearance, improvement of working conditions for the engine driver, enhancement of travelling comfort for the passengers, mounting of new driving units and traction systems, which will allow for the reduction of operating costs, among other things.

The modification of vehicle appearance is designed to make the vehicle look modern and have streamlined shape to reduce aerodynamic drag, which in turn will make it possible to reduce energy consumption.

The modernisation of the engine driver's cabin, both in Electric Multiple Units (EMU) and Diesel Multiple Units (DMU), comprises widening of the cabin and installation of ergonomic consoles and seats adapted to the driver's figure.

To improve the working environment for the engine driver, television cameras are installed to replace conventional mirrors. Consequently, the engine driver has a better view of things happening around the vehicle.

The modernisation and construction directions for the passenger compartments include primarily making the trains accessible for the disabled. For the wheelchair passengers space is isolated onboard the train where the disabled can embark and disembark the vehicle without any problem and they can travel safely. Additionally, the train units are equipped with audio-visual systems that enable deaf or blind people to learn about the current situation onboard the train. Additionally, multiple units are equipped with bicycle racks, which enable the transport of bicycles or skis.

To further enhance travelling comfort onboard the train, ticket or vending machines will be installed to enable travellers to buy tickets, various snacks or soft drinks.

The vehicles are equipped with a surveillance system, which registers developments onboard the train, which gives a feeling of safety to the passengers.

The modernised and brand new passenger cars are equipped with modern train running systems, which enhance travelling comfort due to the application of pneumatic cushions.

The rebuilt locomotives are equipped with environmentally-friendly diesel engines that significantly reduce the air emissions of exhaust gases and consume less fuel. Additionally, fuel consumption metering systems are installed.

Moreover, all vehicles are equipped with an air-conditioning system which improves travelling comfort for the passengers and working comfort for the engine driver.

The new vehicles should be equipped with systems and subassemblies enabling them to exceed speeds of 160 km/h, which in turn will make it possible to reduce the journey duration, thus enabling passengers to save time.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
MECHANICS | MECHANIKA
1-M/2014

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SAFETY AND EFFECTIVENESS OF ROAD CARGO TRANSPORT BETWEEN POLAND AND RUSSIA

BEZPIECZEŃSTWO I EFEKTYWNOŚĆ DROGOWEGO PRZEWOZU ŁADUNKÓW W RELACJI POLSKA–ROSJA

A b s t r a c t

This article raises the question of the optimal choice based on time, cost and safety, of road cargo routes between Poland and Russia. The analysis includes twelve routes running through Lithuania, Latvia, Belarus and Ukraine depending on the estimated costs and travel time. To choose the optimal route, AHP method was used. The article also addresses the issues of safety and liability of the carrier.

Keywords: *cargo between Poland and Russia*, *transport security*, *liability of the carrier*, *the choice of the optimal route due to time*, *cost and safety*

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

W niniejszym artykuleł poruszono zagadnienie wyboru optymalnej – ze względu na czas, koszty i bezpieczeństwo – trasy drogowego przewozu ładunków w relacji Polska–Rosja. Analizie poddano 12 tras przebiegających przez Litwę i Łotwę, Białoruś oraz Ukrainę, w której dokonano kalkulacji kosztów, czasu jazdy. Do wyboru optymalnej trasy zastosowano metodę AHP. W artykule poruszono także zagadnienia bezpieczeństwa i odpowiedzialności przewoźnika.

Słowa kluczowe: *przewóz ładunków w relacji Polska–Rosja*, *bezpieczeństwo przewozu*, *odpowiedzialność przewoźnika*, *wybór optymalnej trasy ze względu na czas*, *koszty i bezpieczeństwo*

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1. Introduction

Road freight transport is still the main mode of transport both in Poland and Europe. The volume of road cargo is shown in Fig. 1. Particularly important is the Polish transport to the East. On the one hand, due to the low fuel prices in Russia and the ability to increase profits, this transport is cost-effective, on the other hand, it is characterized by a high risk, such as theft or lack of return loads. Insurance companies with higher risk awareness of that kind of transportation increased their freight rates for cargo insurance to countries such as Ukraine and Russia. Also, when it comes to opportunities based in the so-called safe parking areas recommended by the IRU (International Road Transport Union) their amount decreases with the distance from the Polish border to the east [6]. It is possible to carry loads from Poland to Russia in several variants, i.e., through Ukraine, Belarus and Lithuania and Latvia. In order to find the best possible option, the analysis of the effectiveness of multiple connections for these countries was made, taking into account driving time, tolls, fuel costs, downtime and security in the parking lots.

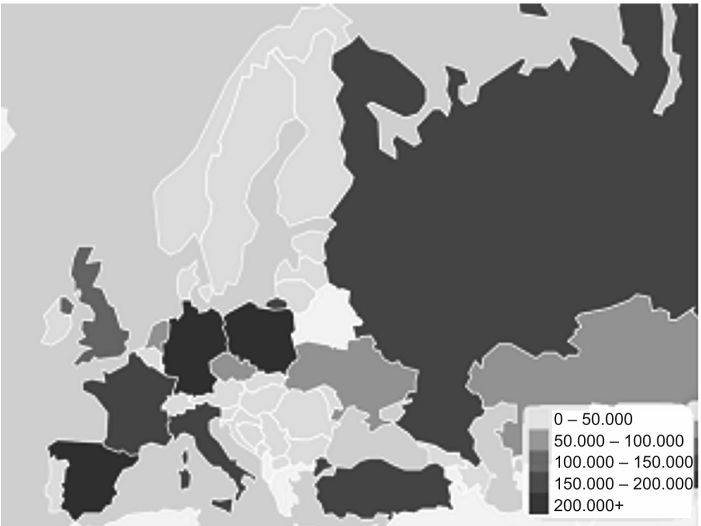

Fig. 1. The volume of road freight transport in Europe data from 2010 (tonne-kilometers in millions) [5]

2. Safety of cargo and liability of the carrier

The laws impose on drivers a requirement to include standstills during payable transportation of cargo and people. The reason for the existence of such legislation is the care for the safety of the driver, cargo and other road users. Despite the fact that the legislation provides driver's legal rest enabling him the proper functioning while driving, it does not guarantee safety during standstills. Very often, prescribed rest is made during stops at gas stations, parking lots and unguarded roadsides [10]. Therefore, it is recommended to plan standstills in places that ensure safety of both the driver and cargo. The list of such parks has been developed by IRU [3]. According to the report of the Polish Chamber of Forwarding and Logistics, more than 73% of transport-forwarding and logistics companies in Poland have at least once become a victim of theft or extortion of goods [9]. In practice, protection against theft of cargo is primarily based on the so-called high-risk goods transport by means of rigid construction such as freezer, isotherm or container, not posting signs on vehicles suggesting the type of cargo and the skillful selection of vehicle standstills places during transit [11].

Responsibility for the transported goods is always on the side of the carrier, so in the case of loss or damage to cargo, they bear the legal and financial consequences. This liability under Article. 65 of transport law excludes the following factors [2]:

– cause attributable to the consignor or consignee,
– forcemajeure,
– giving as incorrect name – incompatible with reality, things excluded from carriage or taken to carriage on special conditions or failure to comply with these terms and conditions by the sender,
– lack of, insufficient or defective packing of the cargo, normally exposed to damage because of their natural properties,
– specific susceptibility to damage because of defects or property,
– loading, stowage or unloading of goods by the sender or the consignee,
– if cargo was damaged by the reasons of the caretaker (supervisor) in the case of carriage which, in accordance with the law or the contract should be supervised.

It should be kept in mind that the actions of third parties such as robberies do not release the carrier from liability. However, through maintaining due diligence and complying with applicable regulations and safety procedures, it is possible to release the carrier from liability in a judicial process.

3. Variants of connections

According to the analysis of the efficiency of cargo between Poland (Wroclaw) and Russia (Kazan), three variants of connection were developed: Poland–Lithuania–Latvia––Russia; Poland–Belarus–Russia; Poland–Ukraine–Russia. For each variant, there were four possible route options: fastest, shortest, cheapest ways with tolls; avoiding toll roads. In all the variants, it was assumed that transport was performed by a single driver.

When analyzing all twelve variants of transport follow the methodology shown in Fig. 2.

For the calculation of fuel costs, average fuel consumption was estimated, depending on the category of the road, based on previous observations from other routes (exploited data directly from the vehicle) which are:

– 32 L/100 km for expressways and highways,
– 34 L/100 km for national roads,
– 36 L/100 km for local roads and main streets,
– 38 L/100 km for other roads.

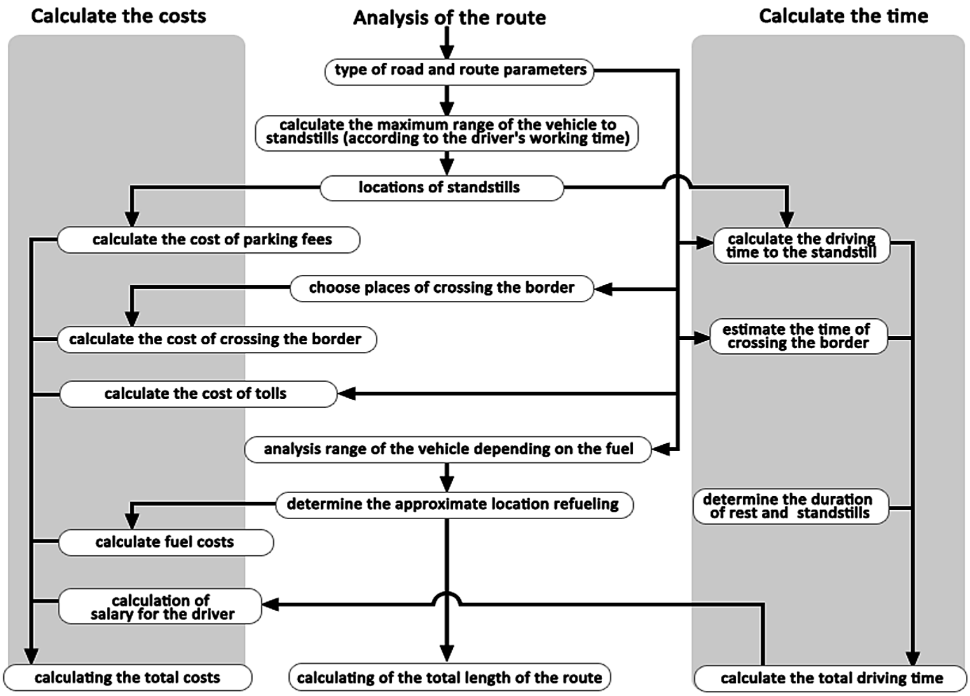

Fig. 2. Methods of analysis developed variants (own study)

The vehicle used by the company meets the emission standard Euro 5. Fuel unit costs were assumed as the average prices in force in that country (Table 1).

Average speeds assumed depending on road category:
- 85 km/h for expressways and highways,
- 70 km/h for national roads,
- 40 km/h for local roads and main streets,
- 35 km/h for other roads.

Table 1

Average fuel prices in the country [7]

	Price [currency/l]	Price [8] [PLN/l]
Poland	5.46 PLN	5.46
Lithuania	76.50 BYR	2.87
Latvia	4.37 LTL	5.30
Belarus	0.90 LVL	5.40
Ukraine	9.90 UAH	3.80
Russia	26.14 RUB	2.72

Movement time of the vehicle is scheduled for one driver in accordance with the current legislation, such as the law on drivers' working time [1]. Resulting from the driver's rest, standstills have been planned to ensure maximum safety for the driver and cargo. Wherever it was possible and a longer standstill was necessary, it was planned to use parks recommended and approved as safe by the IRU organization. Short rest periods, i.e. 15–30 min were planned to provide minimum safety for the driver and cargo and to reduce the cost of paid car parks.

The planning of the transport variant which takes into account these types of standstills could be done only for the route through Belarus. For the two other variants on Russian territory, it was not possible to provide a safe option in all cases, and both routes are characterized by a greater threat than the route through Belarus. For the different analyzed solutions, the most preferred option, in terms of cost and time, is the route shown in Table 2. However, among all these presented alternatives, the best variant is the route between Poland, Belarus and Russia.

For the different variants analyzed, the most favorable option in terms of cost and time were the routes shown in Table 2, where the best solution is to use the route Poland–Belarus–Russia.

Table 2

Summary of the total cost and time of transportation for variants

	Lithuania and Latvia (shortest)	Belarus (fastest)	Ukraine (the cheapest with toll)
Total travel time including stops [h]	87	86	109
Distance [km]	2736	2639	3242
Total costs [PLN]	4460	4700	5142

Plan of routes shown in Table 2 is shown in Fig. 3 together with indications of standstill locations.

Fig. 3. The most favorable option for the analyzed alternative routes (own study)

Due to the diversity of the criteria, for selecting the optimal route AHP method [4] (*Analytic Hierarchy Process*) was used to compare the presented options. There are four main criteria taken into account: travel time; total cost; risk of delays at borders; safety (Table 3).

Table 3

Selection criteria for route variants

Criterion	Lithuania and Latvia	Belarus	Ukraine
Drivingtime [h]	87.00	86.00	109.00
Total cost [zł]	4460.00	4700.00	5142.00
Risk of delays at borders	Large	Medium	Small
Safety	Poor	Good	Poor

The range of scores for each criterion was assumed between 1 and 9. A score of 1 means no priority (the same preference)and 9 is an indisputable advantage (preference).The matrix of priority criteria takes the form shown in Table 4.

Table 4

The matrix of priority criteria

	Drivingtime	Total cost	Risk of delays at borders	Safety
Drivingtime	1	1	1/3	3
Total cost	1	1	1/2	3
Risk of delays at borders	3	2	1	2
Safety	1/3	1/3	1/2	1
Sum	16/3	13/3	7/3	9

However, the matrix of alternative route preference takes the form shown in Table 5.

Table 5

The matrix of alternative routes preferences

	Drivingtime		
	Lithuania and Latvia	Belarus	Ukraine
Lithuania and Latvia	1	1	4
Belarus	1	1	4
Ukraine	1/4	1/4	1
	Total cost		
	Lithuania and Latvia	Belarus	Ukraine
Lithuania and Latvia	1	1/3	6
Belarus	3	1	3
Ukraine	1/6	1/3	1
	Risk of delays at borders		
	Lithuania and Latvia	Belarus	Ukraine
Lithuania and Latvia	1	1/3	5
Belarus	3	1	2
Ukraine	1/5	1/2	1
	Safety		
	Lithuania and Latvia	Belarus	Ukraine
Lithuania and Latvia	1	3	1/3
Belarus	1/3	1	1/3
Ukraine	3	3	1

As a result of the three variants AHP analysis, according to the criteria and score factors presented, the following final scores were obtained:
- Final score for Belarus: 0.46,
- Final score for Lithuania and Latvia: 0.36,
- Final score for Ukraine: 0.18.

Therefore, taking into account not only the cost and time, but also the safety and risks of waiting at the border, we may conclude that, according to these criteria, the optimum route is the route Poland–Belarus–Russia.

4. Route details

The route chosen by the AHP analysis runs through the Polish, Belarus and Russian territories. It is scheduled for 6 short stops and a stop in Terespol at the Belarus-Poland border. On the border of Belarus–Russia it is not required to wait for passage. Detailed information about the route is shown in Table 6.

Table 6

Detailed information about the route variant Poland-Belarus-Russia

Location	Distance [km]	Drivingtime	Parking fee [zł]	Action
Wrocław (PL)	–	–	–	Start
Duchnów (PL)	370	4 h 28 min	–	Short standstill
Terespol (PL)	168	2 h 17 min	–	Crossing the border
Brest (BY)	10	0 h 12 min	–	Short
Baranovichi (BY)	215	1 h 54 min	453	Rest
Borisov (BY)	225	2 h 03 min	–	Short
Orsha-Smoleńsk (BY)	170	1 h 58 min	–	Crossing the border
Khlystovka (RU)	19	0 h 15 min	83	Rest
Uvarovka (RU)	310	4 h 30 min	–	Short
Bakovka (RU)	140	2 h 01 min	94	Rest
Standstill (RU)	140	2 h 00 min	–	Short
Kstovo (RU)	297	3 h 32 min	88	Rest
Standstill (RU)	300	3 h 30 min	–	Short
Kazań (RU)	275	3 h 54 min	–	Stop

In conclusion, the chosen variant of route through Poland–Belarus–Russia can be characterized by:
- Total driving time with standstills: 86 h,
- The total distance: 2639 km
- Total cost (4700 zł) which includes:
- tolls: 997.79 zł,
- fuel: 2534.40 zł,
- parking fee: 718 zł,
- the salary of the driver: 450 zł.

For the entire length the analyzed route allows the use of secure parking for long standstills which reduces the risk of cargo theft or damage. Short standstills can take place at any convenient location without additional dangers.

5. Conclusions

In this paper, twelve cargo road routes between Poland and Russia through Lithuania, Latvia, Belarus and Ukraine were analyzed. Standstills required by law were planned to be realized in safe parking areas. The optimal route (due to time, cost and safety) was chosen with the use of the AHP method. It proved that the optimal solution is the route through Belarus. In addition, the second alternative route passing through Lithuania and Latvia with similar characteristics was set. Although this route is cheaper, it does not allow parking at secured car parks in Russia. The analysis guarantees a good starting point for the final design and routing of cargo between Poland and Russia.

The chosen route has been revised and based on real cargo transport. Execution of the route planned by these guidelines was made possible by the courtesy of one of the Malopolska transport companies, which is engaged in the carriage of cargo, inter alia, in relation to routes from Poland to the east and south.

Narodowe Centrum Badań i Rozwoju

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NEED OF JOINT EFFORTS TO PREVENT ROAD CRASHES DEATH AND INJURIED

WSPÓŁPRACA INSTYTUCJONALNA W ZAPOBIEGANIU WYPADKOM DROGOWYM I OGRANICZENIU ICH SKUTKÓW

A b s t r a c t

This article describes the current situation in the area of European road safety and draws attention to the adverse developments in several Central European countries. It presents the approach of the international project SOL in relation to strengthening road safety management capacity in the region of Central Europe. It underlines the added value of networking and contains recommendations for building multi-stakeholder partnerships for road safety at national, regional and community levels. It also provides a resume of stakeholder assessment undertaken in Zilina region.

Keywords: *safety, networkig*, *multi-stakeholder partnership*, *strategy*, *project SOL*

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

W artykule opisano obecną sytuację z dziedziny bezpieczeństwa europejskiego ruchu drogowego i zwrócono uwagę na niekorzystne zmiany, jakie zachodzą w kilku krajach Europy Środkowej. Zaprezentowano podejście międzynarodowego projektu SOL w relacji służącej do wzmocnienia zdolności zarządzania bezpieczeństwem ruchu drogowego w Europie Środkowej. Podkreślono wartość dodaną sieci oraz zawarto zalecenia dotyczące budowania wielostronnego partnerstwa w bezpieczeństwie drogowym na szczeblu krajowym, regionalnych oraz gminnym. Zawarte zostało również podsumowanie oceny przeprowadzonej dla udziałowca z regionu Zilina.

Słowa kluczowe: *bezpieczeństwo*, *sieci*, *wielostronne partnerstwo*, *strategia*, *projekt SOL*

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1. Introduction

The degree of road transportation and motorization is constantly increasing. Apart from the undoubted advantages, it causes a heavy loading of the road network and places constantly increasing demands on traffic and its safety. Road safety is actually not only an important traffic and social issue, but also an economic one.

There is universal recognition of the tremendous global burden resulting from road traffic crashes, and that road traffic injuries constitute a major but neglected public health problem that has significant consequences in terms of mortality and morbidity and considerable social and economic costs. According to the WHO and the World Bank [4], a multi-sectorial approach is required to successfully address this problem. While the number of deaths and seriously injured people is falling, studies have shown that faster progress is possible if all effective means are applied [3].

Road crashes and road crash injury are no longer seen as 'an inevitable outcome of road transport' but rather as 'largely preventable and predictable'. A core component of this 'new paradigm' is the recognition that road safety is a multi-sectorial issue and a public health issue – all sectors need to be fully engaged in responsibility, activity and advocacy for road crash injury prevention. Good infrastructure and vehicles must be complemented with common sense everyday human behaviours and effective trauma care services [10].

2. The actual traffic situation in Europe

Road safety is a major societal issue in Europe because about 80% of Europeans live in cities. European cities are suffering heavily from congestion high levels of pollution, noise, and road crashes, largely caused by excessive use of the private car. Road strategy depends greatly on how communities choose to manage their transport systems in relation to their overall health and safety objectives and how they are balanced with economic, social and environmental considerations [1]. The growing trend away from public transport, walking and cycling towards motorized transport has marked a move towards modes and means of transport that pose comparatively higher costs to society economically, environmentally, and in health terms.

In 2007, for the first time since 2001, the number of people killed on European roads had not decreased in comparison with the previous year [8].

In Western Europe, the number of road traffic fatalities declined in 2007 by 1.2%. However, this decrease was accompanied by a rise in both the number of casualties (+1.4%) and the number of accidents (+5.6%). These data were strongly influenced by the performance of Turkey which has shown significant increases in all three indicators. In 2007, only the United Kingdom and Greece recorded drops in the number of fatalities, casualties and injury accidents. At the same time Denmark, Finland and Sweden have seen their road fatalities increase by 32.7%, 13.1% and 5.8% respectively.

In 2010, figures considerably changed and we can observe a positive decreasing trend in the number of fatalities, casualties and injury accidents in more western European countries – France, Austria, Spain, Portugal, Ireland, Denmark and Germany. At the same time, the number of fatalities in Greece also decreased, but the number of accidents and injuries increased. Sweden, Luxembourg and Malta have been confronted with a rise in the number of fatalities on their roads by 18% and 13% respectively.

In Central and Eastern Europe, the number of road fatalities increased by 6.4% in 2007. This result is all the more disappointing since at the same time, the region recorded a strong increase in the number of casualties (+6.4%) and number of accidents (+6.7%). With the exception of Bulgaria, Estonia, Hungary and Lithuania, which show a drop in road fatalities, casualties and injury accidents, all other countries have been confronted with a rise in the number of fatalities on their roads.

Table 1

Number of road fatalities in Western Europe [7, 9, 11, 12]

	2007	2008	2009	2010	2007–2006 (%)	2010–2011 (%)
Austria	691	679	633	552	–5.3	–6
Belgium	1 067	944	944	812	–0.2	4
Denmark	406	406	303	255	32.7	–13
Finland	380	344	279	272	13.1	7
France	4 620	4275	4 273	3 992	–1.9	–1
Germany	4 949	406	303	255	–2.8	–13
Greece	1 578	1 555	1 456	1 258	–4.8	–13
Ireland	338	280	239	212	N/A	–12
Luxembourg	43	35	48	32	19.4	13
Malta	12	15	21	15	9.1	13
Netherland	791	677	644	537	–2.5	4
Norway	233	N/A	212	208	–3.7	N/A
Portugal	854	885	840	937	0.5	–7
Spain	3 823	3 100	2 714	2 479	–6.8	-6
Sweden	471	397	358	266	5.8	18
Switzerland	384	357	312	327	3.8	N/A
Turkey	5 004	N/A	N/A	N/A	8.0	N/A
UK	3 059	2 645	2 337	1 905	–7.2	6

In 2010, the situation changed for Lithuania, the Czech Republic, Slovakia, Hungary, Romania and Serbia. They experienced a decrease is the number of fatalities, accidents and injuries on their roads, with the exception of Latvia, which showed a decrease in the number of fatalities, but a drop in road casualties and injury accidents. Countries like Estonia, Poland, Bulgaria and Slovenia saw their fatalities increase by 29%, 7%, 4% and 2% respectively.

Acording to statistics published by The European Commission in the summer, of 2011, EU road fatalities decreased by 11% in 2010. In 2011, the first year of the 2020 Road Safety Target, the overall number of road deaths decreases compared with the previous year, but the reduction slows down (to –2%). This was the slowest decrease in road deaths in a decade (wide reduction throughout the last decade was on average –6%). However, country by country, statistics show that the number of deaths still varies greatly across the EU. Whereas in some European countries, the road safety situation has improved constantly over recent decades, in many others, the road safety challenge has not been addressed so successfully and number of road fatalities is still very high.

Table 2

Number if road fatalities in Central and Eastern Europe [7, 9, 11, 12]

	2007	2008	2009	2010	2007–2006 (%)	2010–2011 (%)
Albania	384	N/A	N/A	N/A	38.6	N/A
Bulgaria	1 006	944	944	812	–3.5	4
Croatia	619	N/A	N/A	N/A	0.8	N/A
Czech Repub.	1 222	1076	901	802	15.0	–4
Estonia	196	132	98	78	–3.9	29
Hungary	1 232	996	822	740	–5.4	–14
Latvia	419	316	254	218	2.9	–18
Lithuania	740	449	370	299	–2.6	–1
Poland	5 583	5 437	4 572	3 908	6.5	7
Romania	2 794	3 061	2796	2 377	12.8	–15
Serbia	962	905	810	656	6.9	N/A
Slovakia	661	622	380	371	8.7	–13
Slovenia	293	214	171	138	11.8	2

This road safety challenge has reached a magnitude that even puts the overall competitiveness, the attractiveness as location for working and investments as well as the quality of life in the most seriously affected parts of the cooperation area at considerable risk. Road crashes have a severe negative impact on the social and economic situation in respective countries, costing up to 2% or more of the GDP [6].

Even though there are several good practice examples of road safety management, serious joint efforts are required by all relevant stakeholders on all levels to make a contribution to reach the overall policy goal set by the European Commission – a decrease in the number of road crashes by 50% in the midterm.

There is a lack of national and local government commitment to road crash/trauma prevention and sustainable transport in many countries.

Even where national strategies exist, the political commitment is often lacking to ensure these policies are properly implemented at all levels of government. Progress in reducing road crashes/trauma and promoting sustainable transport is hampered by the fact that management, implementation and resources are largely concentrated at the national level. In addition, the responsible national departments are thinly staffed and there are generally weak links to community level government to facilitate local level action and enable the implementation of national policies at the community level even though legal frameworks allow for local government action in road safety and transport planning.

At the community level, dedicated multidisciplinary institutional structures to manage effective road safety and sustainable transport programs are generally very weak or entirely absent. This weakness is compounded by a lack of well trained professionals with the knowledge and skills to develop, implement, monitor and evaluate effective long-term road safety and sustainable transport programs, grounded in a multidisciplinary systems approach.

Experience from countries with the best road safety records showed that the delivery of effective road safety and sustainable transport interventions is most successful when action is coordinated among different levels of government, from the national to the community level and different sectors and disciplines. It is important that local government and local professionals are actively involved and supported in the delivery of national policies because they are in the best position to turn national objectives into local solutions.

3. Approach of the SOL project

Based on the findings previously presented and on the fact that the transnational cooperation for mutual learning and the joint development of standards and innovative road safety measures has proved to be the most effective instrument for advancing the quality standards and effectiveness in managing road safety issues, the SOL project initiative was created. The project started in April 2010 and will finish in March 2013.

SOL is a project co-financed by The Central Europe Transnational Cooperation Programme (CEE). It involves 8 central European countries: Austria, Czech Republic, Germany, Hungary, Italy, Poland, Slovakia and Slovenia. It is representing a significant regional road safety programme that is contributing to global road safety with critical experience, tools and knowledge.

The basic objective of the project is the enhancement of capacities of local and regional stakeholders to prevent road accidents in Central Europe. Its main goal is jointly to develop a strategy of road safety that will support the Central European regions in catching up with the highest EU standards in road safety, specifically:

SOL is linked to global work – it seeks to assist communities in implementing the main recommendations of the world report on road crash injury prevention (World Bank), including an overall increase of political commitment towards road safety, developing activities based on evidence rather than "ad hoc", developing strategies and action plans, allocating resources to the main road safety risks, implementing projects, monitoring and evaluating impacts.

The SOL Work Programme is designed to generate a continuous cooperation among different levels of administration on one hand, and different local entities from different countries on the other, to build up a network made of vertical and horizontal connections.

Firstly, a top-down input was applied, as the expert teams reached the local communities and recognized the most active ones in order to supply them with the necessary professional skills and tools to get the awareness of the focal issues concerning their own community. Secondly, the local communities, once endowed with the above described skills and tools, were fostered to get a stable connection with the upper level started in order to communicate the main discovered needs (also thanks to the skills built in the top-down stage) and get an active role in building an action plan and a consequent pilot action, with a bottom-up input.

This cross of top-down and bottom-up inputs is creating a vertical network made of interconnected realities, in permanent cooperation, sharing useful data and knowledge.

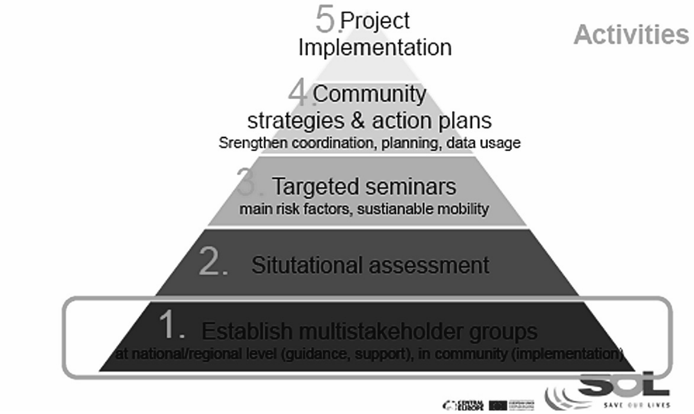

Fig. 1. Pyramid model of the SOL project activities

On the other side, local communities and technical project teams are networking from a horizontal point of view with local communities from different countries, implementing a real transnational cooperation in the field of road safety, sharing data and successful practices in order to reduce the number of fatalities on the roads.

By the end of the project the following tools will be available and disseminated to followers:

- Central European space specific and comprehensive road safety assessment strategy to define the most urgent need for local action.
- Concept for ideal road safety management structures involving regional multi-sector focus groups of all stakeholders.
- Guidelines for jointly elaborating and implementing regional/local road safety programmes and action plans.
- Central European space specific and comprehensive road safety assessment strategy to define the most urgent need for local action.
- Set of good practices for successfully tackling road safety challenges in different fields tailored to the target groups.
- Strategies for raising public and political awareness as a first step towards concrete action in target areas.

As was mentioned above, one of the main objectives of the SOL project is to strengthen road safety management capacity in the region of Central Europe. Currently, road safety management structures differ greatly between countries. In some of them, road safety management and coordination structures that involve multiple stakeholders at all levels of government are well developed. In other countries, coordination structures exist at the national level, but not at the community level. In some, structures exist at all levels of government, but they are not operational or their work is not effective enough.

SOL aims to add value to existing structures, where they exist, and to create a mechanism for coordinating a multi-stakeholder road safety intervention where there is a need and no such structure is in place. The main motivation is to ensure the smooth implementation of the SOL project in the country and there may be additional longer-term benefits as well.

As part of the SOL project, two types of multi-stakeholder partnerships were explored in each SOL country – the national advisory group and SOL community partnership.

The basic step for building the national advisory group and SOL community partnership was undertaking a stakeholder assessment.

The first function of the assessment was identifying the main political figures to be involved in SOL national/regional and community partnership in relation to mobilizing additional financial support and community backing, as well as those with the relevant technical expertise.

The second important function was examining the remit of all the stakeholders and understanding the relationships between them.

Key objectives of this analysis were:

- Identify key stakeholders, define their characteristics and examine how they will be affected by SOL (e.g. their specific interests, likely expectations in terms of benefits, changes and outcomes).
- Assess their potential influence on the development, and implementation of SOL.
- Understand the relationship between stakeholders and possible conflicts of interest that may arise.
- Assess the capacity of different stakeholders to participate and the likelihood of their contributing to the process.
- Decide how the stakeholders should be involved in the process to ensure the best possible quality and viability of the programme, in particular the nature of their participation (e.g. advisers, consultants or collaborating partners), the form of their participation (e.g. member of working group, advisor or sponsor) and the mode of their participation (e.g. individual participant or representative of a group).

The second step of the process of building the national advisory group and SOL community partnership consisted of developing a stakeholder assessment map by looking for answers to the following questions:

A. Identification (of stakeholders)

Who will benefit from SOL and receive the project deliverables (e.g. tools)? Who will work with you to implement SOL, both from your organisation and from the pilot community? Who is considered an expert at the national level from the community about different aspects of road safety? Who serves as your champion in the pilot community? Who is already undertaking road safety activities in the community? Who can help co-finance SOL in the community or from the national level?

B. Interest

What direct benefit do stakeholders expect to get from SOL? What outcomes do stakeholders expect as a result of SOL? What changes will stakeholders be expected to make as a result of SOL? What resources are stakeholders willing (or not willing) to provide for SOL? How do stakeholders feel about each other? Do stakeholders have conflicts of interest concerning SOL? For which stakeholders does SOL help to meet their goals, needs, or interests (or not)?

C. Influence

What legitimate authority do stakeholders have for road safety in the community (e.g., government appointed lead organisation)? From where do stakeholders get their leadership authority (e.g., is it formal or informal)? Who controls strategic resources and decision-making in the community that are important for the successful implementation of SOL? How much negotiating power or influence do stakeholders have over others?

D. Impact

How will each stakeholder impact the project (negatively or positively)? How much will these impacts affect the success of the project? If they can impact the project negatively, how can you prevent or correct the situation? If the project is impacted positively, how can you make the most of it?

4. Road safety situational assessment of Zilina region

The Zilina region, which is located in the northwest of Slovakia, crosses several significant roads. These roads allow a connection of states: Hungary, Austria, Poland and The Czech Republic. Roads- E50, E75, E78, and E442 are the most loaded roads in Slovakia – according to the nationwide traffic census on the road network of the Slovak Republic which was realized in 2010. High volumes of traffic intensity also impact on the number of traffic accidents in the region. The negative trend of the accident rate in the Zilina region is the main reason for participation in the SOL project whose implementation should contribute to solving its problems in the area of road safety.

The objective of the SOL community situational assessment was to compile and present the data needed to assess the road safety situation in the Zilina region, including road crash and injury data, institutional capacity, public opinion and knowledge survey, stakeholder map and main conclusions from the analysis.

The assessment leaded to the identification of priority issues for action and served as a baseline for monitoring and evaluating the impact of the SOL project and its interventions in the communities. Its categories are described in Table 3.

The assessment lead to the identification of priority issues for action and served as a baseline for monitoring and evaluating the impact of the SOL project and its interventions.

The complex problem of solving road safety requires a lot of input data and detailed information which are necessary prerequisites for obtaining a common approach for all the interested organizations and representatives from different disciplines of the national economy. Therefore, an emphasis is given to the identification and analysis of the entities involved in the topics related to road safety.

During the analysis were identified goals of respective subjects, their responsibilities (resulting from actual Slovakian National Road Safety Plan for the period 2011–2020.) as well as evaluated their interests, influence and impact in relation to road safety. Interests and influence of the subjects were evaluated using thee-stage rule:

– **Considerable** – organizations with considerable interests and significant influence on solutions to road safety problems,

– **Limited** – organizations with limited interests and limited influence on solutions to road safety problems,
– **Insignificant** – organizations without significant interests or influence on solutions to road safety problems.

Table 3

Parts of road safety assessment

Category	Purpose of the assessment
Road safety assessment	To strengthen understanding of road crash as and road crash injury situations in specific geographical areas of the pilot community. The information is vital for road safety management and advocacy purposes.
Institutional capacity assessment	To understand institutional strengths/gaps for delivering and managing a systems approach to road safety including multi-stakeholder interventions and for encouraging safe and sustainable mobility. To understand training needs of road safety professionals and community road safety stakeholders
Public opinion survey	To understand public knowledge, opinion about road safety, and to understand travel preferences. The road safety plan must be acceptable to the local population. The results will help in preparation of the road safety plan reflecting on expectations of the local population.
Stakeholder map	To identify stakeholders in the community who can: • participate in the SOL community teams • contribute to delivery of the SOL and community road safety objectives

Impact of subjects on SOL project implementation was evaluated by using three-stage evaluation rules:
– **Great impact** – organizations whose participation on the SOL project implementation is key and for whom project success is desired,
– **Intermediate impact** – organizations whose participation on the SOL project implementation is recommended, they could make a significant contribution to the project,
– **Insignificant impact** – organizations whose participation on the SOL project implementation is recommended but contributions of these organizations are limited.

By analysis and evaluation of actual situation, road safety in the Zilina region was found out that the most numerous representations have organizations from transport area at the situational assessment map. The trade-union composition of these entities should enable a complex problem solving of road safety. However, it will be important to determine the system of management and financing, as well as the management entity, control subject, the mutual cross-links and the scope of competence, which should ensure the effective functioning of the system. The range of competitions should be divided between: police; stations and services responsible for technical control of vehicles; local and regional authorities; education sector, medias, medical organizations; road administrations; insurance companies; producers and car importers; transport organizations; driving schools; motoring associations; research and development organizations.

Creation of this management and funding model will not be easy because this model has not been established either in the territory of Zilina region or in Slovakia so far. However, it belongs among the priority tasks of the national plan to increase the road safety for the period 2011 to 2020.

5. Conclusions

The best global, European and regional examples show that road crash and road trauma prevention can be sustainable. But we need to build on good practic experiences and facilitate long term measurable improvement by empowering local communities and local citizens with the knowledge, skills and networks that they need to work to make their roads safer.

Many countries show similar weaknesses in dealing with road safety issues on the political and technical levels. Political commitment, professional capacity and institutional structures are not robust enough to stem the growing number of deaths and injuries from road crashes. Therefore, a transnational working approach is favoured in order to facilitate mutual learning processes that envisage a higher level of professionalism in dealing with this issue.

Government, business and civil society need to collaboratively and actively participate in programmes for the prevention of road traffic injury through injury surveillance and data collection, research on risk factors of road traffic injuries, implementation and evaluation of interventions for reducing road traffic injuries, provision of pre-hospital and trauma care and mental-health support for traffic-injury victims, and advocacy for prevention of road traffic injuries.

Multi-stakeholder partnerships that bring together different sectors and disciplines within the framework of a targeted "safe system approach" offer the greatest possibility of innovative, comprehensive and sustainable solutions for road crash injury prevention. Their role in the process of the prevention of road traffic crash-related deaths and injuries is crucial.

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WALDEMAR PARKITNY*

ANALYSIS OF QUALITATIVE CRITERIA FOR RAILWAY PASSENGER TRANSPORT BETWEEN CHOSEN VOIVODESHIP CITIES

ANALIZA KRYTERIÓW JAKOŚCIOWYCH DLA KOLEJOWEGO TRANSPORTU PASAŻERSKIEGO MIĘDZY WYBRANYMI MIASTAMI WOJEWÓDZKIMI

A b s t r a c t

The article presents an attempt to use synthetic and partial qualitative criteria to analyse the qualitative workings of railway transport enterprises providing passenger transport on the Kraków–Katowice route. Both cities are capitals of the largest industrial, scientific, cultural, touristic and trade centres in the south of Poland. They are placed a small distance from each other, and thanks to a well developed road and railway net, a quick journey between those cities is theoretically possible.

Keywords: *quality, competition in transport, standard of trip, demand on transport services, synthetic and partial qualitative criteria in transportation, passenger railway transport, transport offer*

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

W artykule przedstawiono próbę wykorzystania syntetycznych i cząstkowych kryterów jakościowych do jakościowej analizy funkcjonowania przedsiebiorstw transportu kolejowego świadczących suługi transportu pasażerskiego na trasie Kraków–Katowice. Oba miasta są stolicami największych przemysłowych, naukowych, kulturowych, turystycznych i handlowych centrów w południowej Polsce. Znajdują się one w niewielkiej odległości od siebie, a dzięki dobrze rozwiniętej sieci drogowej i kolejowej szybka podróż między tymi miastami jest teoretycznie możliwa.

Słowa kluczowe: *jakość, konkurencja w transporcie, standard podróży, popyt na usługi transportowe, syntetyczne i cząstkowe kryteria jakościowe w transporcie, transport kolejowy pasażerski, oferta transportu*

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1. Introduction

The article deals with the situation on the market of railway passenger transport on the Kraków–Katowice route with regard to factors influencing the quality of transport service. Both cities are capitals of voivodeships in which scientific, cultural, industrial and academic life focuses. Moreover, Kraków as the former capital of Poland, is a touristic city well-known in the whole world. Qualitative workings, undertaken by road carriers, aiming at taking over passengers on the discussed route, were described in "Technical Transactions" No. 7-M/2012 in the article entitled *Quality and competition in passenger transport. Case study for passenger road transport* [5], while functioning of railway carrier till the year 2010.

2. Investigative problem and aims of study

The following synthetic criteria of quality, referring to the quality of transport services for passenger transport in cities, are enlisted by Starowicz [12]: accessibility, time of trip, conditions, reliability, ecology.

The aim of the study is a trial of utilization mentioned criteria to qualitative analysis of railway transport enterprises realizing passenger carriage on the route Kraków–Katowice, describing the present state and its estimation.

Transport in that section has been realized by railway (Regio and Inter Regio trains started by Przewozy Regionalne and TLK as well as EC PKP trains started by Intercity S.A.) and bus connections.

The need for analysis came into being as a result of growing criticism relating to the quality of railway services which appeared several years ago in media. The author noticed, that the gap which has originated in consequence of decreasing of passenger train number and extension of their ride times, has been filled by road hauliers offering quicker and often cheaper connections.

3. Range of investigations

The investigations comprised all direct connections between Kraków and Katowice. There have been studied road and railway connections executed by collective transportation.

Different kinds of railway connections being made by railway hauliers in years 2010–2013 as well as road hauliers were examined [5].

4. Investigative methods

The author applied the following investigative methods: observation; analysis of passenger collective road [5] railway transportation hauliers' offers [5] – analysis of individual hauliers time-schedules in different years and periods of their being in force; analysis of transport fares; measurements of real times of rides; random interviews with the hauliers' workers and passengers.

5. Form and range of study

Author assumed, that the study would use described in literature, synthetic and partial qualitative criteria, to analysis of qualitative workings of railway transport enterprises, realizing passenger transports on discussed route. Individual criteria were compared with existing state. Descriptive form of study completed with suitable comparisons in tables has been assumed.

6. Analysis of railway passenger transport services quality basing on assumed investigative methods

The synthetic criterion of accessibility consists of, among other things, the number and share of inhabitants who are in the zone of convenient accessibility to the line of collective transport. In the case of inter-regional connections, the maximum distance travellers are prone to travel to get to the railway station, is 15–20 km. Because that distance makes about 1/4 of the distance between Kraków and Katowice, one can assume passengers would be people living in localities in which trains stop as well as some people realizing obligatory rides, coming to railway stations by passengers cars and continuing their journey by train. Park & Ride car parks situated near the railway stations (e.g. in case of Krzeszowice or Trzebinia) facilitate this way of travelling [2, 8].

Another criterion of quality are connections which allow easiness of making transfers to other means of collective transportation and to passenger cars. Treating a journey on the discussed distance as an indirect one, changing trains in Katowice in the case of a change of platform, would be possible through use of the tunnel and stairs. In Kraków, travellers could use the passage with a tunnel or through the car park located over the platforms. In both cities, using a lift is difficult because of lasting overhauls.

Before the reconstruction of the main station in Katowice in 2010, access to vehicles of municipal transport was better there than in Kraków, but it required using the numerous steep stairs of the flyover. In Kraków, municipal transport stops were situated in several places and some distance from the main station. Qualitative parameters such as access time and time lost on changing trains have been lengthened because of the big distance of the railway station from the municipal transport stops in Kraków, as well as removing the station of municipal communication placed near the main railway station in Katowice in autumn 2010 on account of reconstruction of the main railway station and replacing that with the pavillion on Plac Oddziałów Młodzieży Powstańczej.

Information as well as timetable also belong to accessibility as quality criterion. Timetable realization influences other quality criteria, that is disposability, time and continuity of action (less important in interregional transport, especially facultative). Information was given by means of timetables in the railway station hall, paper timetables and electronic displays on platforms, oral announcements, by the internet and book timetables. After the beginning of Katowice railway station reconstruction, the train departures information displayed on the platforms did not always work properly.

For people using railway connections often, their frequency and regularity are important. In Tables 1 and 2, train departures in each year have been presented and Table 3 presents their number and average frequency.

The analysis of subsequent timetables shows a systematic decrease in the number of connections and an increase in the travel time.

Table 1

Chosen timetables of trains – departures from Kraków to Katowice

Timetable of TLK trains	Timetable of PR trains	Timetable of IR trains	Timetable of IC WAWEL trains
before the change of timetable in December 2010:			
2.33 5.21 5.35	3.54 5.07 6.47	6.05 9.05 13.05	7.24
6.35 7.40 8.35	7.35 9.44 12.36	14.05 15.05 17.05	
9.35 11.35 12.19	13.41 14.18 15.18		
13.35 14.35 15.35	16.16 17.44 20.35		
16.35 17.35 19.35			
19.42 21.54			
after the change of timetable in December 2010:			
0.51 5.28 6.28	3.49 5.10 6.15	6.10 10.35 11.45	7.30
7.35 9.28 11.28	8.55 11.56 14.15	13.10 15.35 18.17	
12.28 13.28 14.28	15.15 17.15 20.15	19.25	
16.28 17.28 18.28			
19.55 20.26 21.45			
timetable valid from 1.08.2011:			
0.51 5.28 6.28	3.49 5.10 6.15	6.10 8.42 10.35	7.30
7.35 9.28 11.28	8.55 11.56*) 13.15*)	13.40 18.28	
12.37 14.28 16.45	14.15 15.15 16.15	20.56 runs in Sunday	
17.38 18.33 20.28	17.15 20.35		
21.14 21.45 22.43 23.42	*) – runs from Monday – Friday except holidays (feasts)		
timetable valid from 1.03.2012:			
5.00 6.02 7.01	3.40 5.11 6.11	8.20 9.36	7.08
10.36 12.50 14.11	8.12 12.11 14.00		
16.09 16.58*) 18.00	16.19 20.05		
18.46*) 21.38*) 22.06			
23.21*) – periodical			
timetable valid from 10.06.2013:			
6.10 8.13 10.23	3.32 5.12 14.46	9.27 10.05 bus	
12.36 14.58 18.20	16.23 20.40	10.06 bus*)	
21.25		18.30 bus	
Source: author's study on the grounds of data available on: www.rozklad-pkp.pl, PKP PLK S.A., PKP Intercity S.A.			

Table 2

Chosen timetables of trains – departures from Katowice to Kraków

Timetable of TLK trains	Timetable of Regio trains	Timetable of IR trains	Timetable of EC WAWEL trains
before the change of timetable in December 2010:			
1.25 4.22 5.07	5.35 6.35 7.42	6.53 10.15 11.15	17.57
7.20 7.55 9.05	8.45 10.46 13.42	12.15 14.15 16.15	
9.55 10.55 11.55	14.42 15.42 16.42	18.15 19.19 20.40	
12.55 13.55 14.55	17.42 18.42 19.58		
15.55 16.55 18.55			
20.25 20.53 21.55			
after the change of timetable in December 2010:			
1.29 4.45 4.55	5.40 6.40 7.40	9.46 11.47 14.50	17.55
6.52 7.15 8.15	8.40 10.40 13.40	17.18 18.55 19.41	
10.15 11.15 12.15	14.40 15.40 16.40		
13.15 14.15 16.15	17.40 18.40		
18.16 19.15 20.15			
timetable valid from 1.08.2011:			
1.56 3.20 4.45	5.40 6.40 7.40*)	6.27 *) 9.46**)	17.55 except
5.55 6.15 6.34*)	8.40 10.40 13.40	11.47 14.49 17.18	23, 24.VI.2011
7.21 8.15 10.15	14.40 15.40*) 16.40	18.55	
11.15 12.15 14.15 16.15*) 18.16 19.15	17.40 18.40*)	*) – runs on Saturday and 1, 11.XI, except 12.XI.11	
20.15		**) – kurs w pn od 5.IX	
*) – runs to Kraków Płaszów	*) – runs from Monday – Friday except holidays (feasts)	2.XI.11, does not run 31.X.11	
timetable valid from 1.03.2012:			
2.02 4.27 5.23*)	5.19 6.28 7.24	16.52	17.50
6.32*) 8.39 9.30	8.17 13.28 14.17		
10.27 11.56 12.27	15.27 16.18 18.30		
14.54 16.27 18.38	19.08		
19.41 20.30			
*) – periodical			
timetable valid on 10.06.2013:			
3.20 4.47 9.08	5.17 7.25 14.24	7.30 bus, 9.30 bus	
10.45 13.13 14.59	15.07 16.11 18.22	12.15 bus, 14.05 bus	
18.12 21.23		17.40 bus, 18.44 bus*)	

Source: author's study on the grounds of data available on: www.rozkład-pkp.pl, PKP PLK S.A., PKP Intercity S.A.

Tabela 3

Number (*n*) and frequency (*f*) of running trains for different timetables

n	*f*	TLK trains	Regio trains	IR trains	EC WAWEL trains
from Kraków to Katowice:					
A	–	17	12	6	1
B	–	15	9	7	1
C	–	16	9+2 z[2)]	5+1[9)]	1
D	–	10+3[*)] – periodical	8	2	1
E	–	7	5	1+3[*)] – bus	0
–	A	85 min.	120 min.	240 min.	1440 min.
–	B	96 min.	160 min.	206 min.	1440 min.
–	C	90 min.	160/131 min. z[2)]	288/240 min. z[9)]	1440 min.
–	D	144/111 with periodical	180 min.	720 min.	1440 min.
–	E	206 min.	288 min.	360 min. with bus	lack of connection
from Katowice to Kraków:					
A	–	18	12	9	1
B	–	15	11	6	1
C	–	14 + 2[1)]	8+3[2)]	4+1[3)]+1[4)]	1
D	–	12+2[5)] – periodical	10	1	1
E	–	8	6	6 – connection by bus	0
–	A	80 min.	120 min.	160 min.	1440 min.
–	B	96 min.	120 min.	131 min.	1440 min.
–	C	103[5)]/90 min.[6)]	180/131 min.[7)]	360/288 min. z[3)]/ z 240 min.[4)]	1440 min.
–	D	120 min./103 min.[8)] with periodical	144 min.	1440 min.	1440 min.
–	E	180 min.	240 min	240 min. – connection by bus	lack of connection
Source: author's study on the grounds of data available on: www.rozkład-pkp.pl, PKP PLK S.A., PKP Intercity S.A.					

where: *n* in first column means:
A – before the change of timetable in Decmber 2010,
B – after the change of timetable in Decmber 2010,
C – timetable valid from 1.08.2011,
D – timetable valid from 1.03.2012,
E – timetable on 10.06.2013,
[1)] runs to Kraków Płaszów,
[2)] runs Mondays–Fridays without holidays (feasts),
[3)] runs on Saturday and 1, 11.XI, except 12.XI.11,
[4)] runs on Mondays from 5.IX and 2.XI.11, does not run 31.X.11,
[5)] without runs to Kraków Płaszów,
[6)] with runs to Kraków Płaszów,
[7)] with runs from Mondays–Fridays without holidays (feasts),
[8)] with periodical trains,
[9)] runs on Sunday.

A quality parameter that should be connected with travel time is ticket price, which should correspond with the travel conditions, such as, for example: comfort in the train; getting on and off conditions; moving conditions; staff politeness etc.

Travellers of the second class passenger train travelling the 78 km distance from Krakow to Katowice paid 17.10 zł. The Inter Regio trains were more expensive. The second class ticked cost 18.90 zł. These trains, like the former ones, were Przewozy Regionalne (PR) owned and they were fast passenger trains.

The cost of a similar journey by Tanie Linie Kolejowe (TLK) was 23 zł for second class and 35 zł for first class (2013).

Unfortunately, the higher cost does not equal a higher level of service. One of the basic parameters that influences the connection quality assessment is the travel time between the places discussed. This time, according to the old internet timetable of 2010 ranged from 102 min. for the Inter Regio train to 125 min. for the passenger train (Regio). The new timetable extended that time even more from 110 min. for the EC train to 125 min. for TLK trains travelling from Katowice to Krakow, as well as from 103 min. for the EC train to 121 min. for both TLK and Regio trains. The given times are however theoretical ones, it happened quite often that the real travel time reached even 140 min. and the trains were delayed even at the beginning of the journey. This equates to a speed of 33,5 km/h.

The analysis of a chosen timetable of 2011 (valid from 1.08.2011) shows that the expected journey times on the Katowice–Kraków Główny distance were 120–121 min. for PR trains, 115–123 min. for TLK trains, 113–118 min. for Inter Regio trains and 112 min. for the EC Wawel train. Journey times in the opposite direction were 116–121 min. for PR trains, 109–123 min. for TLK trains, 106–109 min. for Inter Regio trains and 103 min. for the EC Wawel train. As can be observed, the travel time from Katowice to Kraków is slightly longer and the travel time of different types of trains is similar, even for the more expensive EC trains, whose travel time was not much shorter from that of the significantly cheaper Inter Regio trains.

Journey times on the Katowice–Krakow in 2012 (example timetable valid from 1.03.2012) were 134–151 min. for PR trains, 120–151 min. for TLK trains, 137 min. for Inter Regio trains and 124 min. for the EC Wawel train. Journey times from Kraków to Katowice, according to the timetable valid from 1.03.2012, were 125–140 min. for PR trains, 121–143 min. for TLK trains, 126–129 min. for Inter Regio trains and 121 min. for the EC Wawel train. A shorter planned time from Kraków to Katowice can be observed here, too.

Trains going from Katowice to Kraków, according to the timetable of 10.06.2013, reached their destination in: PR: 137–151 minutes; TLK: 139–153 minutes; Inter Regio trains did not run and were replaced by buses with a journey time of 75 minutes. Journey times from Kraków to Katowice were: PR: 135–152 minutes; TLK: 133–145 minutes; Inter Regio: 136 minutes. It is important to pay attention to the fact that some of the railway connections, including those being realized by Inter Regio, were replaced (like in the case of the journey in the opposite direction) by bus connections, with a travel time of only 73–75 minutes, and so about 2 times shorter than the railway connections. Buses realized their ride on a highway, without any breaks. The same discounts as in trains were valid there and tickets could be bought from the conductor on the vehicle.

The analysis of the above mentioned data suggests 3 conclusions:

1) seeing that the travel time of different types and different train carriers is almost equal, trains being counterparts of former fast or express trains (TLK, Inter Regio, EC) have lost their main advantage which was a shorter travel time,
2) buying much more expensive ticket for TLK, Inter Regio and EC trains is not economical on the basis that the most important factor which is reduced travel time on such a short distance,
3) while comparing prices and travel times of railway and road connections, the choice of road connections is much more economical.

For comparison, it is proper to quote the results of different investigations relating to the quality of railway services. Those investigations have been made by the questionnaire method "distributed to travellers after getting on the train with the request to fill them in during the journey. Thanks to that, one could be certain that answers to the questions had been given by people who really used the defined connection and were able to estimate particular in a reliable way the qualitative parameters asked about in the questionnaire" [9].

The investigation was executed for the route Kraków Główny–Warszawa Centralna for the following train types: Inter Regio of Przewozy Regionalne; TLK PK Intercity; EIC PKP Intercity; Tarnów–Nowy Sącz for the following train types – RegioPlus of Przewozy Regionalne and REGIO of Przewozy Regionalne; as well as for the route Kraków Główny––Częstochowa for TLK PKP Intercity trains [1]. The investigated passengers had to estimate the qualitative parameters mentioned in the questionnaire on a 1–5 scale, where 1 marked the weakest opinion and 5 the best opinion.

The general degree of satisfaction for all kinds of trains and routes was 3,41, and connections on the route Kraków–Warszawa of TLK PKP Intercity gained the most points – 3.65.

In the ranking of the total average marks for different carriers and routes, the travel time by train was in 7th place out of 11 analysed qualitative parameters (3.15 points from a maximum of 5), and it was the best result estimated on the Kraków Główny–Warszawa Centralna route, where trains are run by Centralna Magistrala Kolejowa. "However, even here, good marks were not gained. Maybe the consciousness of the fact that already some time ago, this route could be run in a time of even about 30 minutes shorter than now, caused that the dispersion of marks was from 3.32 to 3.79" [6, 7].

The frequency of trains was estimated even worse (10th place and 2.92 points). Ticket price achieved a considerably better 4th position (3.32 points). It is important to notice that on the section Kraków–Częstochowa, both the parameters received the worst marks of all (2.5 points for the frequency of trains running and 2.6 points for the travel time) which stand in contrast with the ranking of travellers' preferences of W. Starowicz, in which the investigated travellers gave a high priority to the frequency of vehicles running; it gained a high 3rd place [12, p. 51].

The quoted results of the investigation can prove a large significance that travellers attribute to both frequency and travel time. Driving the highway between Katowice and Kraków takes from 55 minutes by bus at night to 80 minutes during the day. As such it is often comparable with the time of going through the city in rush hour. So, this journey becomes an interesting and competitive alternative as compared to, for example, purchasing or renting a flat in a city to which the access is easier. This alternative is interesting for people forced to travel because of their workplace or their studies. In that situation, one can also suppose that travellers' preferences relating to municipal collective transport would be similar in discussed range to preferences in the range of trip in the discussed section.

The waiting time as a parameter of transport quality is connected with the frequency of vehicles running. This criterion can be significant in a situation where passengers did not manage to get on the vehicle because of over-crowding or they had been late and are waiting for the next train. In Table 3, the number and frequency of trains running by the timetables of the years 2010–2013 have been presented. Values given as times of departure are the average values for twenty-four hours and the actual waiting times for the next train of the same carrier are different depending on the time of day. Long waiting times, sometimes exceeding the journey time, can cause a change of carrier.

Other analysed qualitative criteria are time and continuity of action, including the night transport service, trains of TLK, operating also at night, have been better than road carriers running only during a day and in the evening till 2012 (Tab. 1 i 2).

Achievement of journey destination in a specified time is a qualitative criterion belonging to reliability. Considering this criterion, in the case of railway carriers there have been delays.

The stability of line arrangement and timetable belongs to the line arrangement, which is the next qualitative. In the case of railway carriers, lines arrangements are invariable, but in the discussed period there have been often timetable changes, being valid [13, 15, 16]: from 1.03.2011 to 31.05.2011, from 1.06.2011 to 31.08.2011, from 1.09.2011 to 28.10.2011, from 29.10.2011 to 10.12.2011, from 11.12.2011 to 31.03.2012, from 1.04.2012 to 31.05.2012, from 1.06.2012 to 28.06.2012, from 29.06.2012 to 2.09.2012, from 3.09.2012 to 15.10.2012, from 16.10.2012 to 8.12.2012, from 9.12.2012 to 9.02.2013, from 10.02.2013 to 13.04.2013, from 14.04.2013 to 8.06.2013, from 9.06.2013 to 1.09.2013, from 2.09.2013 to 19.10.2013, from 20.10.2013 to 14.12.2013. Apart from the changes mentioned above, corrections to timetable have additionally been made in the case of some connections, and there have been exclusions and seasonal changes in trains running, e.g. 6 for 13 trains of TLK from Kraków to Katowice, mentioned in the timetable valid from 11.10.2011, had additional changes of departure times. Because of that and the admissible content of the article, selected timetables were used in the present analysis.

The regularity of services is another qualitative parameter. TLK (in both directions) and Regio (from Katowice to Kraków) could boast the largest regularity in railway transport after the change of timetable in 2010 and 2011. Unfortunately, hours of departures in later years were irregular and timetables were difficult to remember.

In the case of ecological criteria, such as passengers' personal safety, it seems that road carriers are better, whereas according to statistics, the threat of accidents is smaller in the case of railway transport. Considering bad condition of tracks on the discussed section, railway transport can also be connected with noise and vibrations.

7. Recapitulation

Running a transport activity is connected with risk, which was documented in [3]. That risk consists of, among other things, a risk relating to competition's workings. It can be reduced, complying with proving rules of marketing. The basic tools of marketing are: product; price; promotion; distribution; staff [4]. Among the most often quoted definitions of quality, one can mention these, which say that quality is a collection of the characteristics of a product or service as well as the extent to which customers' expectations are fulfilled by them.

Since November 2012, travellers have been able to use a new railway station located at 3 Maja Street in Katowice. Unfortunately, reconstruction of some platforms, building a shopping centre, reconstruction of the street mentioned above and the exchange of tram track-ways have made using it difficult at the time of writing this paper. Investigations made in 14 cities in Poland show that the directness of trip, in other words, trips without any vehicle changes, is the most important factor from 10 studied features relating to preferences of the quality of collective transportation services [12, p. 51]. Removing of some municipal and agglomeration bus stops as well as interregional bus stops, previously situated directly near the station, in the location of the shopping centre that is currently being built, and the necessity of walking a considerable distance to the railway station, can be a factor which can discourage some travellers from using railway connections, especially the elderly, people of limited motoric possibilities as well as families with children.

As it appears from the analysis, railway carriers realize transport postulates mentioned above to a different degree. Factors which can be crucial in a relatively short distance, especially for obligatory transport, are low price and short journey time. Comparing the offers of railway carriers and road carriers, we can notice that two road carriers are especially active on that route, that is INTER Sp. z o. o. and Uni – The Bus, outweigh the offers of the railway carriers in respect to price (14 zł in 2013), time of journey (75–80 min.), frequency (twice an hour) and regularity (the same lapse of time – every half an hour – in both directions) [9, 10].

8. Conclusions

Among the most important conclusions, one can mention:

1. The majority of synthetic and partial qualitative criteria being applied in municipal collective transportation can be used to analyse qualitative workings of railway transport enterprises realizing passenger transports.
2. On the analysed section, a decrease in the number of rides being made, especially the cheapest connections by Regio, has been observed during last years. Those trains stop at all stations and passenger halts. The decrease in their numbers makes transportation with other localities difficult, especially in the case of obligatory trips.
3. The decrease in the number of train rides number is the accomapnied by an extension of journey times and the increase of ticket prices, e.g. since 2011 till 2013 for passeenger trains of 2nd class from 15 on 17.10 zł, from 16 on 1890 zł for Inter Regio, from 19.50 on 23 zł for TLK, and for 1st class of TLK trains from 27 on 35 zł.

4. A significant improvement of used rolling-stock has not been noticed.
5. An intensification of road hauliers workings, which assure the shorter time of ride, low prices and better rolling stock has been observed.
6. All these factors can influence a change of passengers' transport habits and further decrease of railway transports part.
7. Workings tending towards modernization of exploited railway infrastructure on this section, assuring decided shortening of ride time and trip comfort improvement as well as the exchange of rolling-stock are essential.

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APPLICATION OF NEURAL NETWORKS FOR OPTIMISATION OF SIGNALLING IN ROAD TRAFFIC

ZASTOSOWANIE SIECI NEURONOWYCH DO OPTYMALIZACJI STEROWANIA SYGNALIZACJĄ ŚWIETLNĄ W RUCHU DROGOWYM

A b s t r a c t

This article presents a proposal for applying neural networks to control road traffic. The proposed solution makes it possible to determine durations of traffic signals at intersections so that the waiting time for transit is as short as possible. The variability of traffic intensity on all access roads and between analysed intersections was taken into account. The developed concept was compared with a method of determining the durations of lights based on the coefficient of intersection readiness, and the feasibility for practical applications of the method was assessed.

Keywords: *neural networks*, *road traffic*, *traffic signals*

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

W artykule przedstawiono propozycję wykorzystania sieci neuronowych w sterowaniu ruchem drogowym. Proponowane rozwiązanie umożliwia wyznaczanie czasów trwania sygnałów świetlnych na skrzyżowaniach, tak aby czas oczekiwania na przejazd był najmniejszy z możliwych. W analizie uwzględniona jest zmienność natężeń ruchu na wszystkich drogach dojazdowych oraz między analizowanymi skrzyżowaniami. Opracowaną koncepcję porównano z metodą wyznaczania czasów trwania świateł opartą na współczynniku gotowości skrzyżowania i scharakteryzowano możliwości praktycznego zastosowania metody.

Słowa kluczowe: *sieci neuronowe*, *ruch drogowy*, *sygnalizacja świetlna*

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Designations

k_{gc} – readiness koefficient [–]
T_{pc} – full light cycle time [s]
T_{zi} – duration of green light [s]
T_{zcz} – duration of yellow light and yellow and red light [s]
T_{pp} – time for a vehicle to travel through the crossing [s]
T_{sr} – mean waiting time in traffic [s]
Q_i – intensity of vehicles [1/60 s]
dt_{12} – temporary shift of signal display between crossings [s]
l_{pr} – number of traffic lanes [–]

1. Introduction

The difficulties of vehicular road traffic are visibly onerous for all involved. Such phenomena are particularly severe in municipal agglomerations, where many drivers travel relatively short distances. This brings about a rise in exhaust emissions and excessive fuel consumption, both harmful to the environment. The dense road network most often found in municipal areas makes it possible to change direction quickly and reach any desired point in the city. On the other hand, the necessity for crossings decreases the capacity to accomodate intersecting directions of traffic, which leads directly to the formation of traffic jams and prolongation of travel time.

One solution applied to improve traffic capacity and to keep traffic moving is the construction of crossings with grade separations. However, these solutions are expensive, and their construction requires space, which is at a premium in the urban environment. Thus, crossings at grade level, with traffic controlled by signalling, are most common.

Below, a proposal for analysis of road traffic through the application of a neural network is presented. It was compared to analysis of the readiness coefficient presented in work [3] and the potential for its practical application was assessed.

2. Analysis of the coefficient of readiness for transit through intersections

Due to speed limits, organisation of traffic at crossings, the number of road lanes in a given direction, and the fact that cars that have stopped must resume driving, there is a theoretical limited number of vehicles that can travel through a given crossing within a unit of time. The effectiveness of signalling control at a given crossing is indicated by the actual number of vehicles coming from different directions that can traverse this crossing within a unit of time. The greater this number under given conditions of traffic variability, and the closer to the theoretical limit value, the more effective the control.

Due to the variability of traffic intensity over the course of a day, a week, or even a season, the most effective method of traffic management should be real-time continuous signalling control. To make this possible, it is necessary to apply systems to determine traffic intensity on access roads to the crossing and to apply controls adapted to such intensities, so that the waiting time for travel through a crossing is kept as short as possible under given conditions for vehicles on all access roads.

The authors presented one form of signalling control in [3], proposing a method maximizing the coefficient of readiness determined for a single crossing. In this method, the duration of green lights is determined based on the maximisation of the crossing's readiness coefficient, which ensures minimisation of the mean waiting time for travel by vehicles heading in both directions. An additional condition was assumed: mean waiting times should be equal in both directions. The total coefficient of crossing readiness is the sum of coefficients for individual traffic directions, according to dependency [3]:

$$k_{gc} = \frac{T_{ziA}}{T_{pc} + T_{srA}} + \frac{T_{ziB}}{T_{pc} + T_{srB}} \tag{1}$$

$$k_{gc} = \frac{T_{ziA}}{T_{pc} + \dfrac{n_a(C) \cdot T_{pp} \cdot T_{pc}^2}{C \cdot l_{prA} \cdot T_{ziA}}} + \frac{T_{ziB}}{t_{pc} + \dfrac{n_B(C) \cdot T_{pp} \cdot T_{pc}^2}{C \cdot l_{prB} \cdot T_{ziB}}} \tag{2}$$

where:

- T_{pc} – full light cycle time (constant),
- T_{ziA} – duration of green light in traffic direction A,
- T_{ziB} – duration of green light in traffic direction B,
- T_{srA} – mean waiting time in traffic direction A,
- T_{srB} – mean waiting time in traffic direction B,
- t_{zcz} – duration of yellow light and yellow and red light,
- C – time constant, e.g. $C = 3600$ [s],
- $n_A(C)$ – intensity of vehicular traffic in traffic direction A relative to constant C,
- $n_B(C)$ – intensity of vehicular traffic in traffic direction B relative to constant C,
- l_{prA} – number of traffic lanes in direction A,
- l_{prB} – number of traffic lanes in direction B,
- t_{pp} – time for a vehicle to travel through the crossing.

To solve the optimisation problem at assumed values of vehicular traffic intensity ($n(C)$), the duration of green lights may be determined for intersecting traffic directions A and B [3].

In actual conditions, it is frequently observed that the formation of traffic jams does not only concern one crossing, but two or more. In this way, characteristic areas with significantly more difficult traffic and increased transit time are formed. To keep traffic moving to the extent possible in such an area, the need to consider traffic intensity and signaling at several adjacent crossings seems to be justified.

The computational model proposed below considers not one but two crossings as well as the number of vehicles arriving at them, constituting an introduction to the development of the problem involving a greater number of crossings. The duration of the appropriate signals determined according to the model makes it possible to minimise waiting times for transit through both crossings, under given conditions of traffic intensity, for all arriving vehicles. Such a solution makes it possible to improve traffic flow in the entire area, not only at one crossing.

In real conditions, both randomness and periodicity play a part in the variability of traffic intensity [1, 2]. To determine all traffic possibilities and find optimal solutions for them through signal control is difficult. Simplified solutions, based on the development of several control programmes for a given crossing, can be encountered in traffic control; such solutions are activated according to the traffic intensity or time of day [1].

The application of neural networks makes it possible to account for variability and randomness of traffic without first finding solutions for all possible scenarios, and to determine optimal durations for signals.

3. Characteristics of the method

A concept for signal control using artificial neural networks is presented below. The implementation of the proposed solution should enable easy, continuous, and fluid signal control in a given area, so that the transit time through this area for increased and variable traffic intensity can be reduced as much as possible.

The crossings presented in figure 1 include only one traffic direction for the main road and access for vehicles from subordinate roads only from the right side of this road. For the opposite direction on the main road, the situation can be considered analogously by accounting for the appropriate intensity of vehicular traffic on the main road and access roads which are opposite to their counterparts on Fig. 1. The computational model remains unchanged, except that the intersection marked 1 is marked 2 for the opposite direction, while intersection 2 becomes intersection 1. This model will still not account for conditional turns or left turns; however, the developed concept has broad possibilities for further development and improvement, which may lead to the full reflection of the nature of traffic in a given area and the determination of optimal control in subsequent steps. The first version of the solution presented here is provisional, and only after it has been positively verified will it be subjected to further modifications.

The intersection system accepted for analysis is shown in the graphic below.

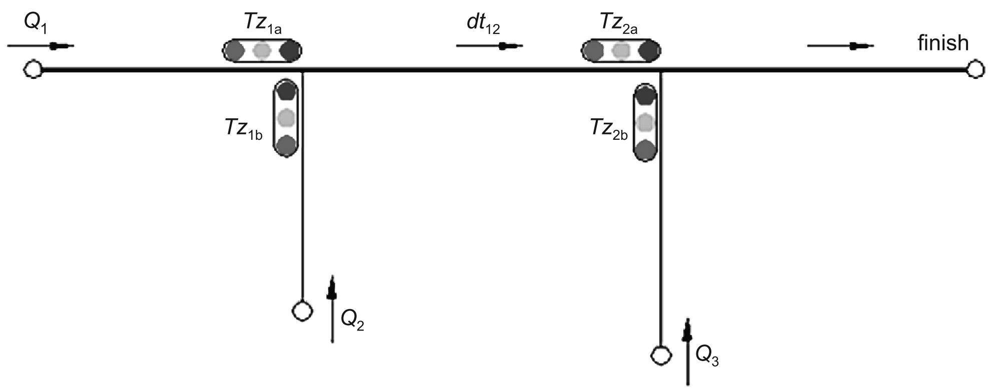

Fig. 1. Schematic of the intersection system accepted in the computing model

Because the proposed model is a simplification of actual road traffic, it is necessary to define specific assumptions:

- the total duration of the green and red light at each intersection is equal to 120 [s] (a yellow light is equivalent to a red light, in accordance with valid road traffic regulations) in both directions,
- optimisation is conducted according to the criterion of the minimum mean value of transit time of vehicles arriving from 3 directions over a time of 30 [min.],
- the distance between intersections is 200 [m],
- the main road is one-way, with one lane, and cars arriving from the two subordinate roads must turn right,
- conditional turns are not taken into consideration.

In the conducted simulations of vehicular traffic, the following are variable values:

- Q_1 – intensity of vehicles arriving from starting point 1 [1/60s],
- Q_2 – intensity of vehicles arriving from starting point 2 [1/60s],
- Q_3 – intensity of vehicles arriving from starting point 3 [1/60s],
- T_{z1} – green light duration at crossing 1 [s],
- T_{z2} – green light duration at crossing 2 [s],
- dt_{12} – temporary shift of signal display between crossings 1 and 2 [s].

The computer programme simulating vehicular traffic calculated the mean transit time of all cars for various configurations of the above variables. Given the duration of each simulation, it is not possible to verify all cases, so variable values are assumed at certain numerical intervals in successive tests. Next, time cases T_{z1}, T_{z2}, dt_{12} are selected for the minimum transit time at determined traffic intensity values Q_1, Q_2, Q_3.

Such a parameter set, for which a minimum mean transit time exists, has been used to 'teach' the neural network presented in Fig. 2.

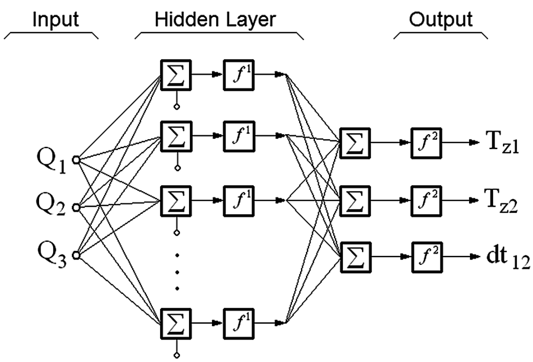

Fig. 2. Schematic of the artificial neural network for signal control

Input and output data were scaled to the range (0; 1) at the beginning in order to ensure their homogeneity.

The learning process was conducted using the gradient method [4–7]. It is based on inputting successive learning vectors into the network and adjusting weight values depending on the error of the obtained network response, so that in further learning steps, the mean square error for the entire learning set decreases. The achievement of a minimum value, which remains unchanged during successive learning steps, means that the learning process has been concluded. In the analysed case, the error decreased only after the 25th learning step, after which its value did not change.

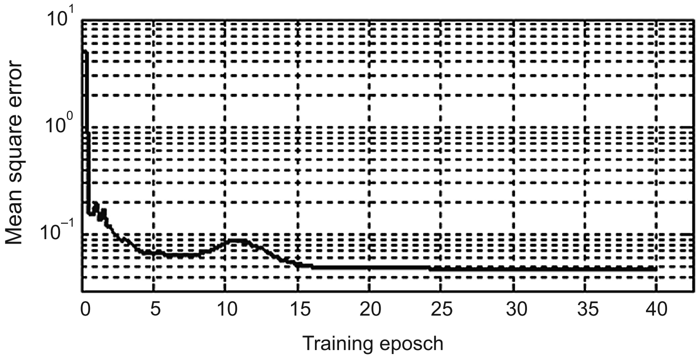

Fig. 3. Mean square error in learning process

One of the conditions guaranteeing the efficiency of the network is the provision of the appropriate amount of learning data, which should be greater than twice the number of weights in the network. In this case, the number of data sets is equal to 100, and the number of variables, for 4 neurons in the hidden layer, is 28, which means that the network will not learn enough based on the analysed data, which in turn could cause the calculation of incomplete time values for signalling changes.

Following the learning process, weight values are not subject to change and become constant values. A network taught in this way, with defined weight values, can then be simulated with any input values. Simulation of an artificial neural network means that data vectors with any values are input and conversion takes place according to constant weight values. In this case, the actual number of vehicles coming from individual directions and on the basis of this number, signalling is controlled continuously based on traffic intensity.

The primary advantage of artificial neural networks is their ability to acquire and generalise, that is, to approximate data. Thus they enable the calculation of the signal changing time in cases of vehicular traffic intensity not found in the learning set during the learning process but which may occur under actual traffic conditions. This makes it possible to control road traffic continuously in real time, using for example, induction sensors built into the road to measure the number of vehicles coming from particular directions.

4. Verification and interpretation of obtained results of calculations

Calculations according to the presented method were carried out for the assumed traffic intensities on individual roads according to Fig. 1. The accepted numerical values are presented in Table 1 and in Fig. 3. It was assumed that the light cycle time at each intersection is equal to 120 [s].

Table 1

Vehicular traffic intensity on individual roads

Vehicular traffic intensity [veh./min.]	Case number											
	1	2	3	4	5	6	7	8	9	10	11	12
Q_1	12	12	12	12	6	12	18	24	12	12	12	12
Q_2	6	12	18	24	6	6	6	6	6	6	6	6
Q_3	6	6	6	6	12	12	12	12	6	12	18	24

After doing the simulation calculations using the neural network (according to Fig. 2), results were obtained as durations of green lights in individual traffic directions, which, according to the presented method, should ensure the shortest mean time of transit for all vehicles through the analysed area from Fig. 1. The obtained results are presented in Fig. 5.

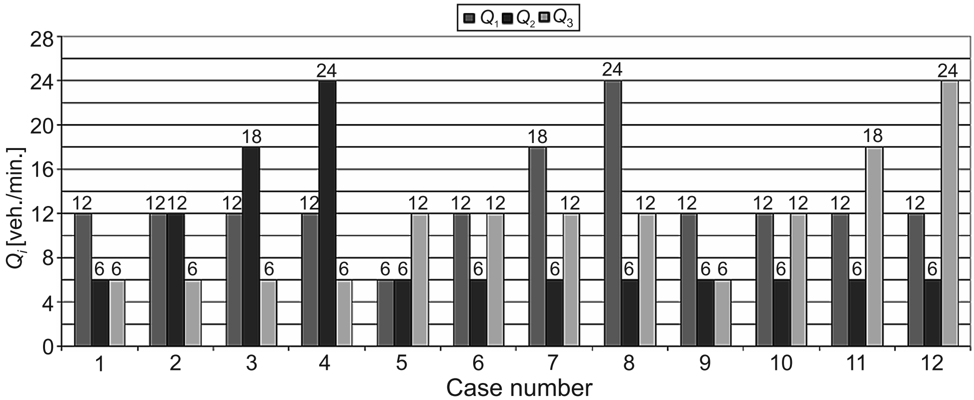

Fig. 4. Vehicular traffic intensity on individual roads accepted for calculations

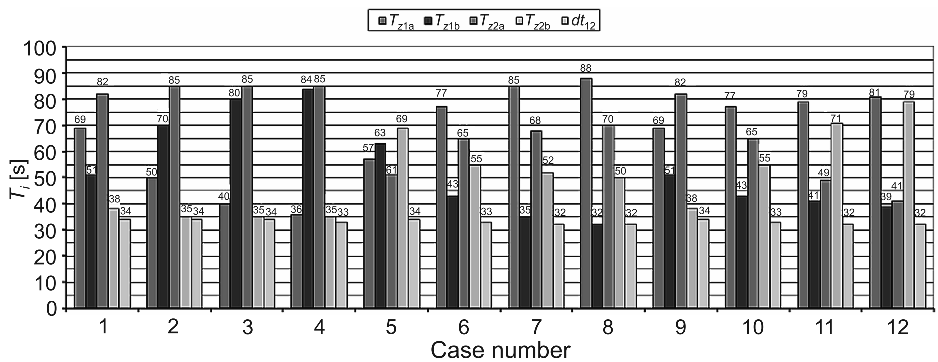

Fig. 5. Green light durations determined by the neural network

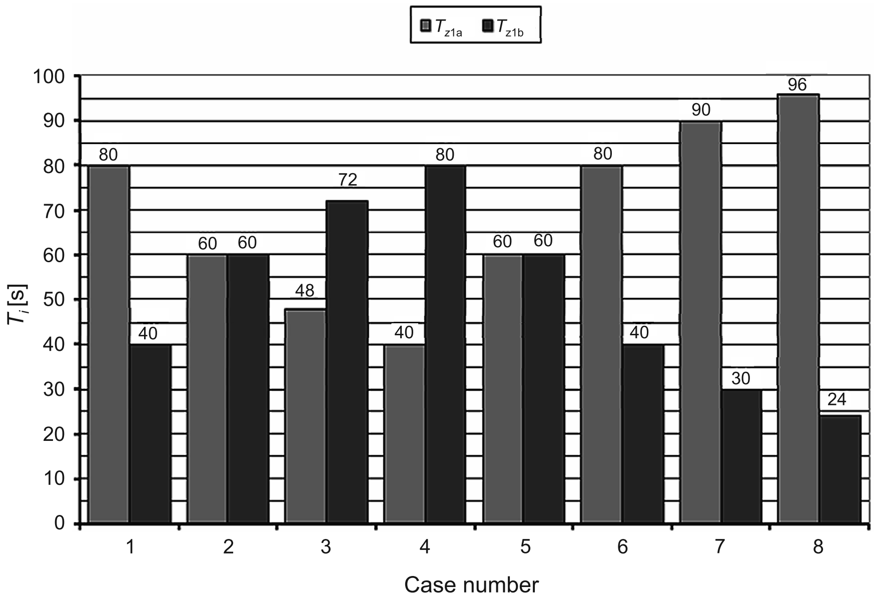

Fig. 6. Green light durations according to the readiness coefficient method

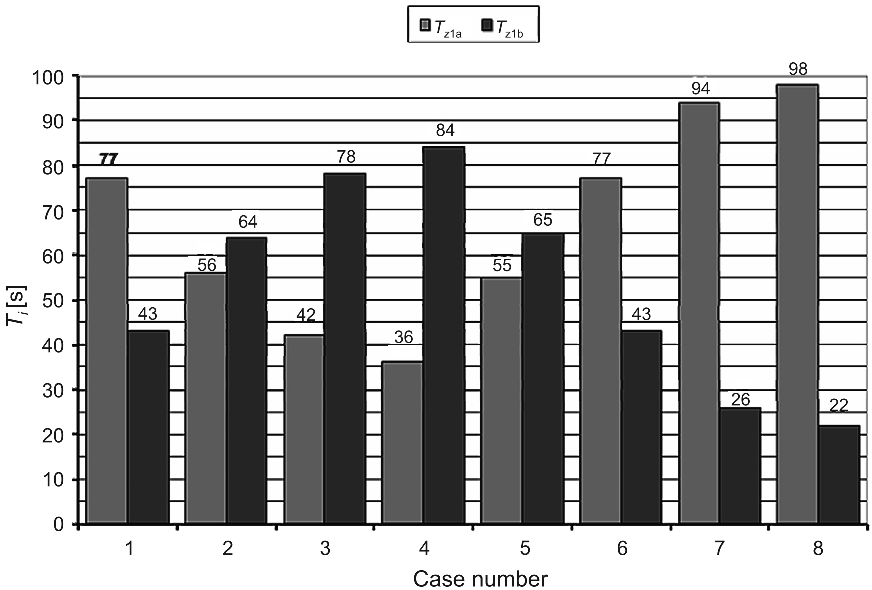

Fig. 7. Green light durations according to the neural network method

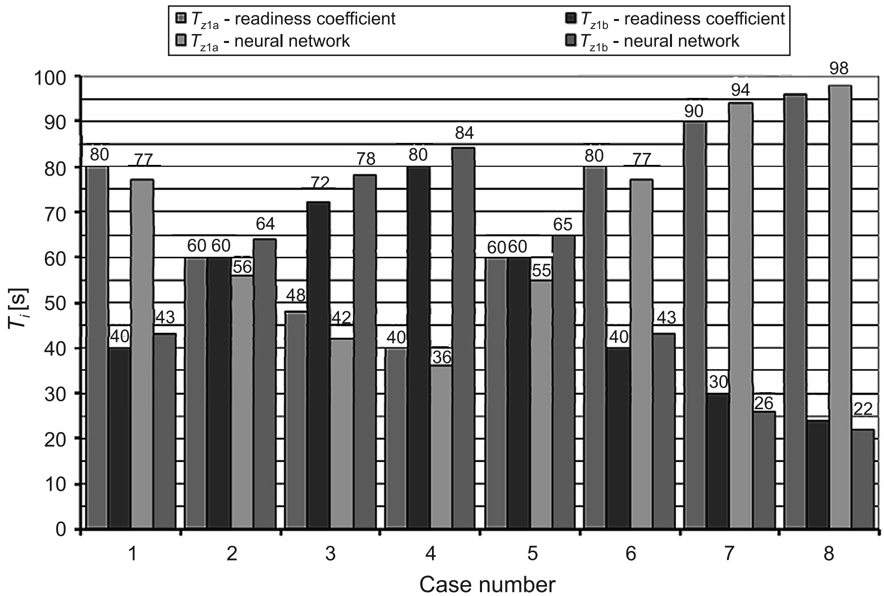

Fig. 8. Results of calculations according to the readiness coefficient and neural network methods

It can be seen that the obtained results indicate the need to prolong the duration of the green light as vehicular traffic intensity increases in a given direction, which is in accordance with reality and expectations. The neural network used for calculations also accounted for the fact that the time of T_{Z2a} must ensure transit of vehicles that are found between crossings 1 and 2, comprising streams Q_1 and Q_2. To obtain the effect of minimising waiting time for transit in this situation given the assumed distance between intersections, time lags between signals at intersections 1 and 2 are required (Fig. 5).

In order to compare the obtained results with the method according to the readiness coefficient mentioned in section 2, calculations were carried out for the case of a single intersection. Calculations were done for the first 8 cases according to Table 1, involving intensities Q_1 and Q_2 only, since only one crossing was being considered. The obtained results are presented in Fig. 6, 7 and 8.

It can be seen that the results obtained by the two computing methods are very similar. The maximum difference was equal to 15%. Most results differed by less than 10%. However, the method using the neural network is more flexible, enabling solutions for cases not considered earlier and the consideration of a greater number of crossings.

5. Conclusion

The traffic analysis methods presented above are two of the many ways to search for solutions of vehicular traffic control through signalling. Their practical applicability determines their efficiency. The adaptation of the presented methods to actual conditions requires the consideration of a greater number of crossings and of intersecting two-way traffic.

Following analysis of the problem, practical verification of such methods and their further development in terms of adaptation to real conditions is warranted. The presented methods may be useful in the analysis and control of road traffic.

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MACIEJ SZKODA*

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).

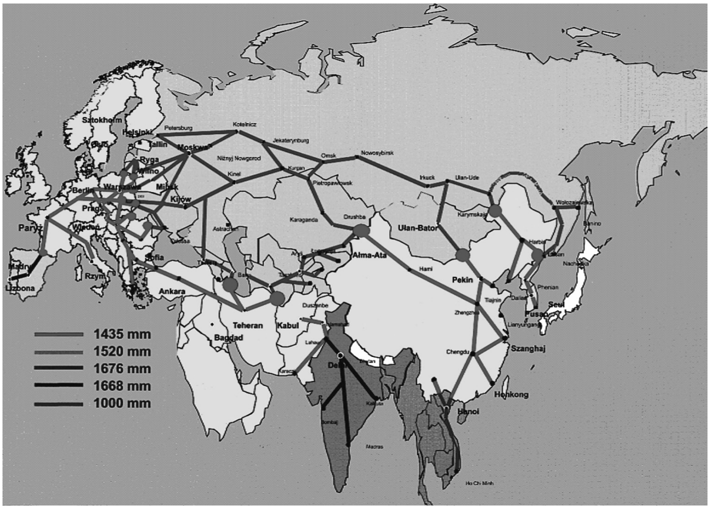

Fig. 1. Variety of the track gauge on the European-Asian continent [11]

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.

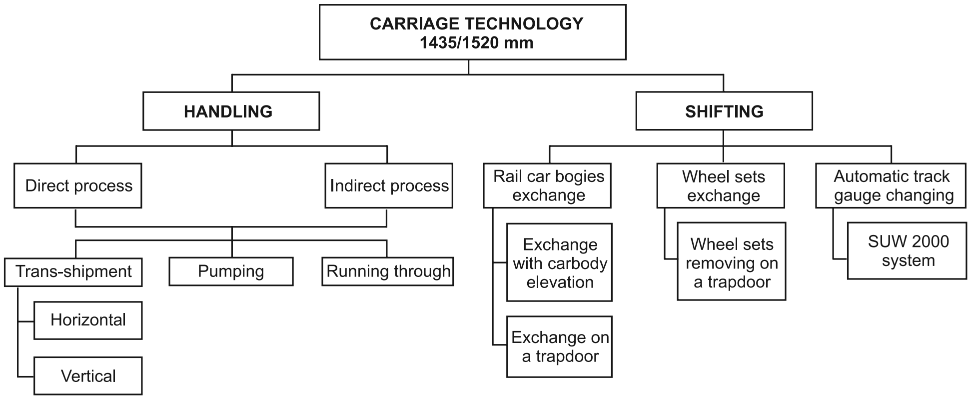

Fig. 2. Techno-organization variants of railway gauge change [6, 12]

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).

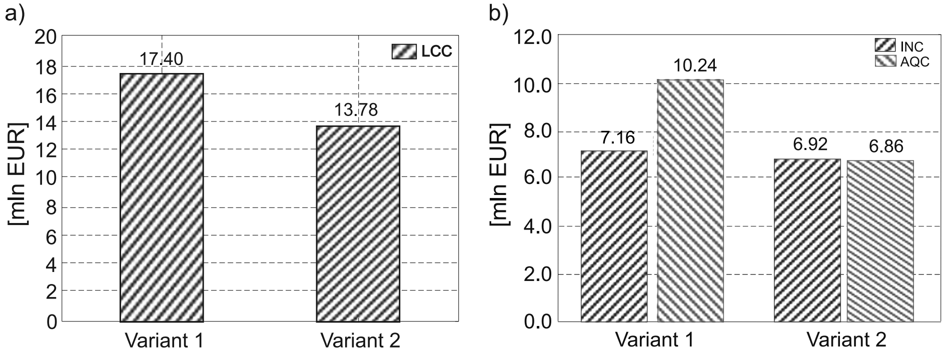

Fig. 4a) LCC of analyzed variants, b) Investments costs INC and acquisition costs AQC

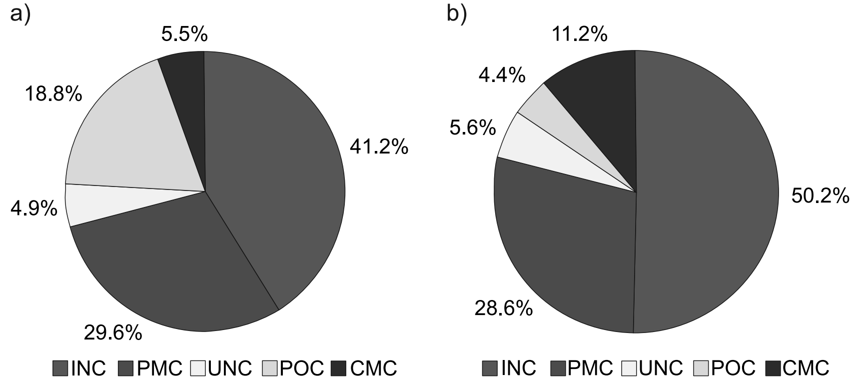

Fig. 5. Share of elementary costs categories in LCC: (a) variant 1, (b) variant 2; INC – investments cost, PMC – preventive maintenance costs, UNC – unavailability costs, POC – operation personnel costs, CMC – corrective maintenance costs

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

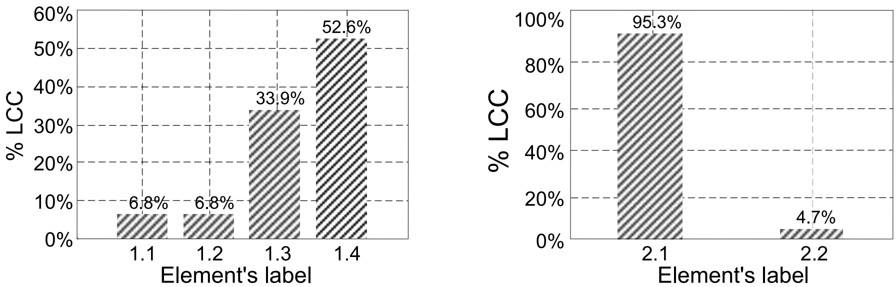

Fig. 6. LCC in system breakdown structure, a) variant 1, b) variant 2

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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PAWEŁ WIĘCEK*, AUGUSTYN LORENC**

INTEGRATED, SUSTAINABLE APPROACH TO THE MANAGEMENT OF URBAN FREIGHT TRANSPORT – REVIEW OF THE WORLD'S SOLUTIONS

ZINTEGROWANE, ZRÓWNOWAŻONE PODEJŚCIE DO ZARZĄDZANIA MIEJSKIM TRANSPORTEM TOWARÓW – PRZEGLĄD ŚWIATOWYCH ROZWIĄZAŃ

Abstract

The purpose of this article is to propose the concept of an integrated system-wide approach to the management of urban freight transport. This work also addresses the aspects of environmental and social impacts from the road freight transport in a confrontation with modern and eco-efficient solutions in this area taken in cities areas the world.

Keywords: *freight transport*, *integrated transportation and logistics systems*, *city logistics*

Streszczenie

Celem niniejszego artykułu jest przedstawienie koncepcji zintegrowanego podejścia systemowego do zarządzania transportem towarów w obszarach miejskich. W szczególności poruszono problematykę niekorzystnych oddziaływań środowiskowych i społecznych, pochodzących od transportu drogowego towarów i dokonano przeglądu nowoczesnych i efektywnych ekologicznie rozwiązań w tym obszarze, podjętych w światowych metropoliach.

Słowa kluczowe: *zintegrowane systemy transportowe i logistyczne*, *logistyka miejska*

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1. Introduction

Over the last few decades, the rapid development of science and technology began a process of fast population growth in the world. Man, who until now has been a neutral part of the perfectly balanced environment is, **now its** major threat. Along with economic growth and intensifying globalization processes, higher levels of the consumption of goods and services can be observed. This results in increasing freight traffic **which** adversely affects the environment and human surroundings. The common consumer lifestyle and the dynamically changing demand for goods and services poses producers and suppliers with high requirements in the field of transport and logistics activities. **Especially** in heavily urbanized area in the centers of large cities, they have to ensure a satisfactory level of customer service, **simultaneously taking into account the** environmental aspects.

2. The volume of road freight transport in Europe and its negative environmental impacts

According to the latest report of the Department of Economic and Social Affairs of the United Nations, strong urbanization processes taking place during the last century caused a significant increase in the number of residents in the cities. In 2009, nearly 3.5 billion of the total world's population lived in urban areas. Many forecasts suggest an extension of this number to about 4.5 billion by 2020 and to 6.3 billion by 2050 [16]. As a result of this trend, there is an urgent need for the supply of goods in different cities, which also translates into growing traffic congestion. Fig. 1 shows the amount of cargo transported within the European Union with regard to different modes of transport.

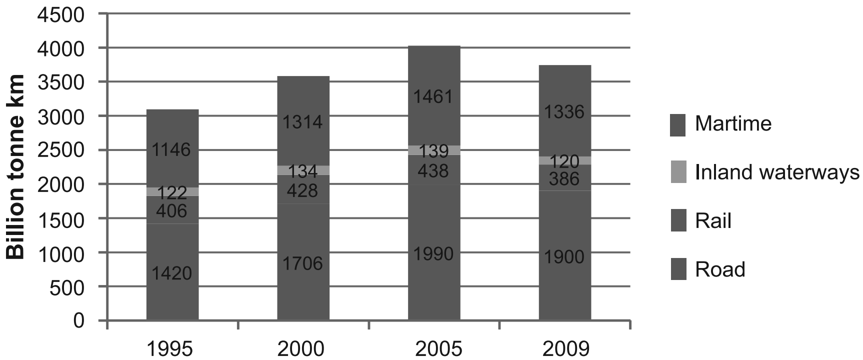

Fig. 1. Number of transported goods in the EU, depending on the modes of transport [4]

The interpretation of this graph shows that road transport continues to be the dominant branch in freight transport within the European Union. The main proof of this fact is that transport activity amounted to 1.9 billion tonne-kilometers in 2009. Also in Poland, road transport plays the most major role in the movement of freight and its level constantly increases, see Fig. 2.

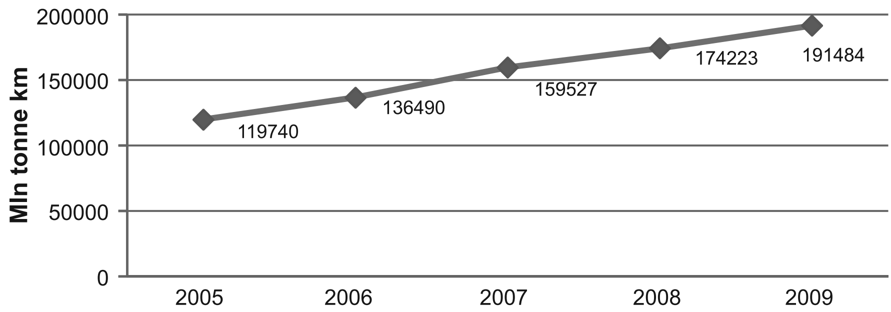

Fig. 2. Freight transport in Poland in the years 2005–2009 [6]

2.1. The impacts of freight transport on the environment

The growing traffic presents simulate certain inconveniences to the local population, contributing to congestion, deterioration of safety for pedestrians and private vehicles and lowering the quality of life in the city. Road transport is on the top of the list of different types of human activities that lead to environmental degradation. Its direct risks come under three separate categories: social impacts; economic impacts; environmental impacts, see Fig. 3.

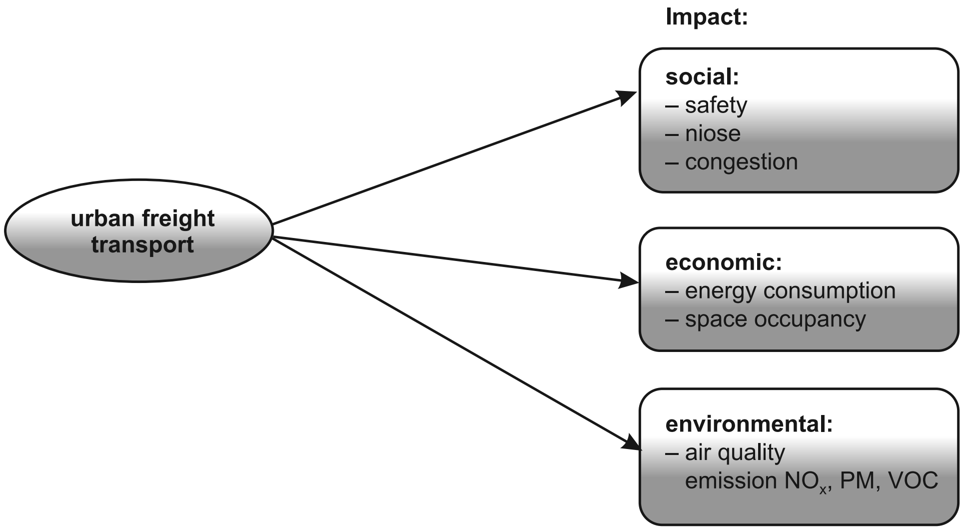

Fig. 3. Impacts of road transport on different environment

2.2. The impacts of freight transport on human health

The most serious impacts to human health is pollution emitted to the atmosphere by road transport. It contains mainly oxides of nitrogen, benzene and carbon, volatile organic compounds (VOC), and particularly dangerous emissions of particulate matter (PM).

Mixtures of these contaminants tend to change over time and space, depending on a number of features, such as close proximity to the road, the type and age of the vehicle, traffic patterns, and the presence of other sources of contamination. Short or long term exposure to these compounds in the air can lead to very adverse health effects immediately or in later years, in the form of the respiratory, nervous and cardiovascular diseases, as well as cancerous changes. According to measurements made by the WHO, vehicles still produce a large share of the emission of toxic compounds [9].

Other negative effects of road freight transport are related to noise and vibration. Nowadays, traffic noise is a serious threat to peace within the major cities and roads. It has a negative impact on health and human working conditions. It is believed that a noise level of upto 30 dB is harmless to the human body, but the level of 34–70 dB causes various concentration difficulties. Above these values, noise is dangerous to health. The above problems will be intensified, because of traffic level increase within the city. It is largely caused by motor vehicles from four main sources: the drive line system: engine; exhaust system: tires interacting with the substrate. In many passageways, noise magnitude depends mainly on commercial vehicles. Often, it is assumed that in terms of noise, one truck is equivalent to eight cars [8].

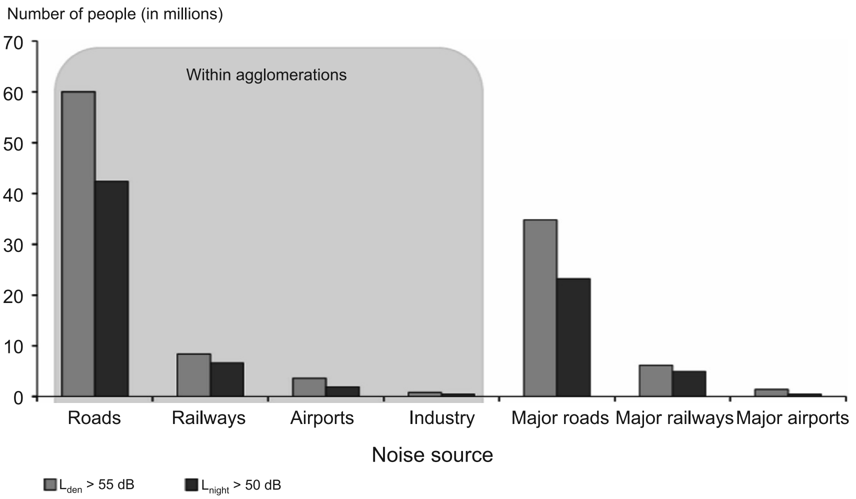

Fig. 4. Number of EU population living in urban area exposed to increased noise level [4]

According to the European Environment Agency, a large part of the EU's city population still live in conditions of exposure to elevated noise levels, see Fig. 3.

3. The proposal of an integrated approach to freight transport management in urban areas

The rising level of consumption of goods, the aforementioned negative environmental and social effects of transport, as well as increasing customer demand for logistics services currently make freight management problems in large metropolitan areas a matter of particular importance. It is the result of the fact that effectively functioning freight transportation system conditioned to a high degree the economic development of cities. Transport activity within large urban complexes underlie the concept of city logistics.

This concept is defined as the process of total optimization of all transport and logistics activities by transport companies including the external environment, congestion and energy consumption in a market economy [14].

Current environmental awareness is a cause of increasing social demand for more sustainable and eco friendly urban transport. According to this evidence, an integrated approach to freight transport management in the city is becoming more and more popular in the world. The overall objective of this concept is to increase the efficiency of transport processes and the distribution of goods, expanding and enhancing services, simultaneously taking environmental issues into account.

The innovative basis for this approach is the fusion of each solution from three directions: logistical innovation, policy factors and technical improvements. It should be considered that each of those elements cannot be treated separately, but should interact with others in integrated way. This means consistent and complementary action of public and private entities in the supply chain network, despite their frequent conflicts of interest [11].

In a wider perspective, presented in a number of scientific papers, integrated and sustainable approach to logistics and transport activities is also recognized in the context of the entire supply chain, because in the long run, it allows for the achievement of even greater benefits. It is commonly believed that a sustainable eco-supply chain promotes efficiency and synergy among its participants, helps to increase eco-efficiency and quality of service while minimizing the economic and social costs [13]. Therefore, the approach to an integrated, sustainable transport of goods in urban areas in the context of the entire supply chain networks can be illustrated by the following graph. See Fig. 5.

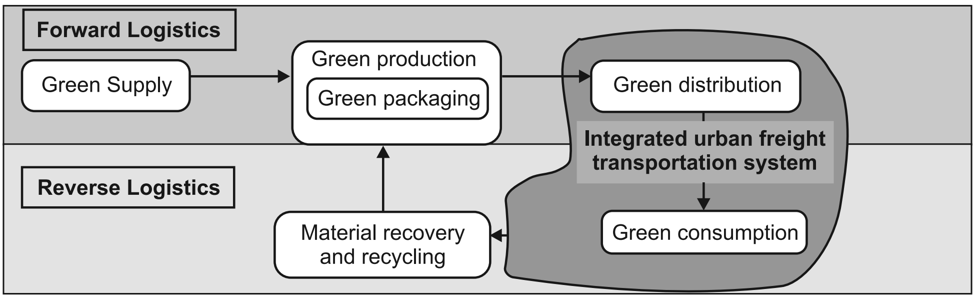

Fig. 5. Integrated, sustainable urban freight transportation system in the context of the whole supply chain network

In line with the vision of sustainable transport of goods, the activities carried out in this area requires the tasks of both forward and reverse logistics.

3.1. The integrated problems of logistics and freight transport in cities

In order to make the transportation system more sustainable and friendly to the environment as well as the urban population, it is essential to make a careful examination of the system's built and of its principles of operation in the context of identifying the problems and providing later solutions. A significant number of published work in this area indicates an important aspect, the presence of many groups of stakeholders, which include: shipping companies; storage companies; transport and courier operators; residents; municipal authorities. Each of these is in an attempt to achieve its objectives, which are often different. Therefore, the level of effectiveness of the logistics and transport operations is often reduced as a result of insufficient interactions between the actors of the system. The quality of the tasks carried out in the area of urban freight transport is also associated with solving various kinds of decision-making problems with different time horizon. The following levels can generally be identified:

– **strategic level**: Decisions made at this stage relate to the long-term issues consider the optimal transport and logistics network structure(centers of logistics and recycling, warehouses, fleet vehicles type) and other organizational and management tasks, which provide financial and economic efficiency. At this level, its initiatives and actions may be taken also by the municipal authorities.
– **tactical level**: Decisions at this level are related to the assessment of the efficiency and effectiveness of use of the transport infrastructure and reliability of supply. In this layer, transport companies take questions choice of equipment, vehicles, infrastructure for the exchange of information and data processing. At this stage there are analysis of the system behavior under uncertainty, incidents, changes in traffic and demand conditions, using mathematical and simulation tools.
– **operational level**: Activities carried out at this level are short term, they are often done from day to day. For example, the task of scheduling and time synchronization processes in warehouses, logistics centers; the issue of optimal allocation vehicles, choice of routes and the sequence of customers visited, including their time requirements.
– **the level of real-time control**: This layer provides some control over the tasks scheduled at the operational level. At this level, decisions and actions are made in real-time when there is a need for a dynamic response to a situation in which there are differences between the planned situation and the state of the transport system in reality. Activities at this stage depend to some extent on the decisions taken at a higher layer. They are sensitive to the quality of operational scheduling, where inefficiency predictions and forecasts can lead to costly changes planned activities through real-time layer.

3.1.1. The role of urban consolidation centers in an integrated urban freight transportation system

According to J. Allen, an important part of the functioning of an integrated and sustainable transport system for goods is an appropriate logistics network structure, taking into account the existence of urban goods distribution centers. Situated on the outskirts of the city, they are designed to manage their assigned areas. A consolidated flow of goods from different companies is brought to customers with smaller, low-emission vehicles. This type of center offers the possibility of storing, sorting, consolidation of cargo groups and other services related to accounting, or legal advice through. Undertaken numerous projects including Italy, Sweden, it indicates a reduction in the total number of kilometers made by nearly 30%. The use of such a solution, however, requires complex cooperation between companies in the planning of tasks and procedures, as well as support for advanced information and telecommunications systems [2].

3.1.2. The aspects of information management in the transport of goods

A key element of an integrated transportation system is the acquisition, processing, management and exchange of data and information, not only within a single company, but also between all the actors in the supply network. Of particular note deserves a real time information, collected and kept updated. From the point of view of system performance, such data relates primarily to the current level of congestion, travel time, service and incidents. From the perspective of customer needs, there is information on the changes in demand, time windows, etc. This allows for effective planning, controling and monitoring of all the processes taking place in the transport and logistics network. To this end, the integrated use of the latest achievements in the field of electronics, telecommunications, advanced positioning systems, data processing and vehicle technologies is becoming more and more common. This gives a basis for the development of sophisticated applications and ICT systems (Information and Communication Technologies), used in the management of transport, logistics and fleet operations. See Table 1.

Table 1

ICT systems used in freight transport

Type:	Tools and technologies used:
On-board systems	– GPS, AVL, navigation and automatic vehicle location, – mobile internet, PDA (Personal Digital Assistants), – ADAS (Advanced Driver Assistance Systems) support of drivers's work, – RFID (Radio Frequency Identification) identification of freight, – Smart cards, electronic tachographs, storing information about the level of load, – on-board sensors, monitoring the condition of the vehicle, transported goods, speed, automatic toll collection.
Off-board systems	– CAD (Computer Aided Dispatch) computer support shipments, – FMS (Fleet Management Systems), comprehensive tools to control, fleet coordination, allocation of means of transport, optimization of capacity utilization, – EDI (Electronic data Interchange), standardized electronic exchange of transaction documents, – DSS, ES (Decision Support Systems, Expert Systems), decision-making tools to support the planning and management.

Management of information in an intelligent way, using ICT systems can have a positive effect on economic issues for transport and logistics companies. It may increase the competitiveness of services, reduce the number of kilometers traveled by vehicles, as well as improve decision-making processes at various levels and companies capabilities of a dynamic response to changes in the network. It should also recognize the positive impact on enhancing road safety, reducing road traffic congestion and improving local air quality [7].

With regard to aspects mentioned in this paper, the proposed concept of an integrated, sustainable approach to transport goods in an urban area can be represented by a diagram. See Fig. 6.

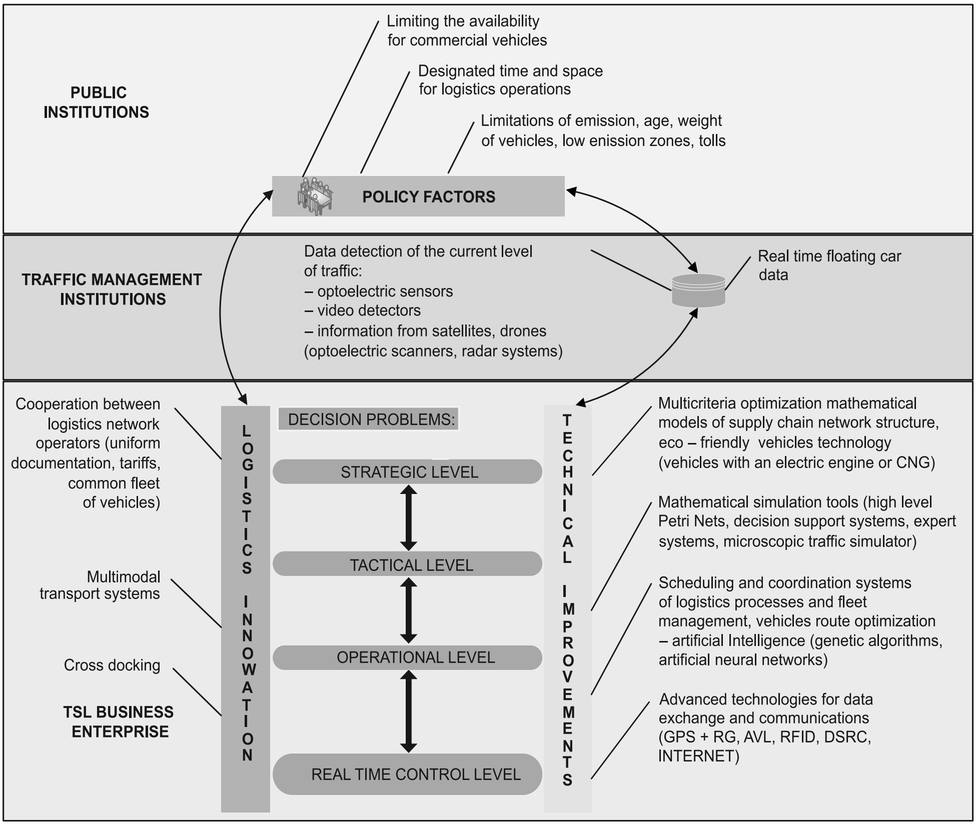

Fig. 6. The concept of integrated and sustainable approach to freight transport in urban areas

The above figure shows how this system can be seen in the context of decision making, tasks and innovation. The three most important factors determining the effectiveness of such an approach (logistics innovation, technical improvements and political factors) cooperate and interact with each other, ensuring a consistent system. The interconnection of these components results in apparent interaction and integration of entities engaged in transport and logistical activities at the organizational, infrastructure, telecommunications and information technology level. The functioning of the system under consideration can be described by using the following conceptual diagram (see Fig. 7).

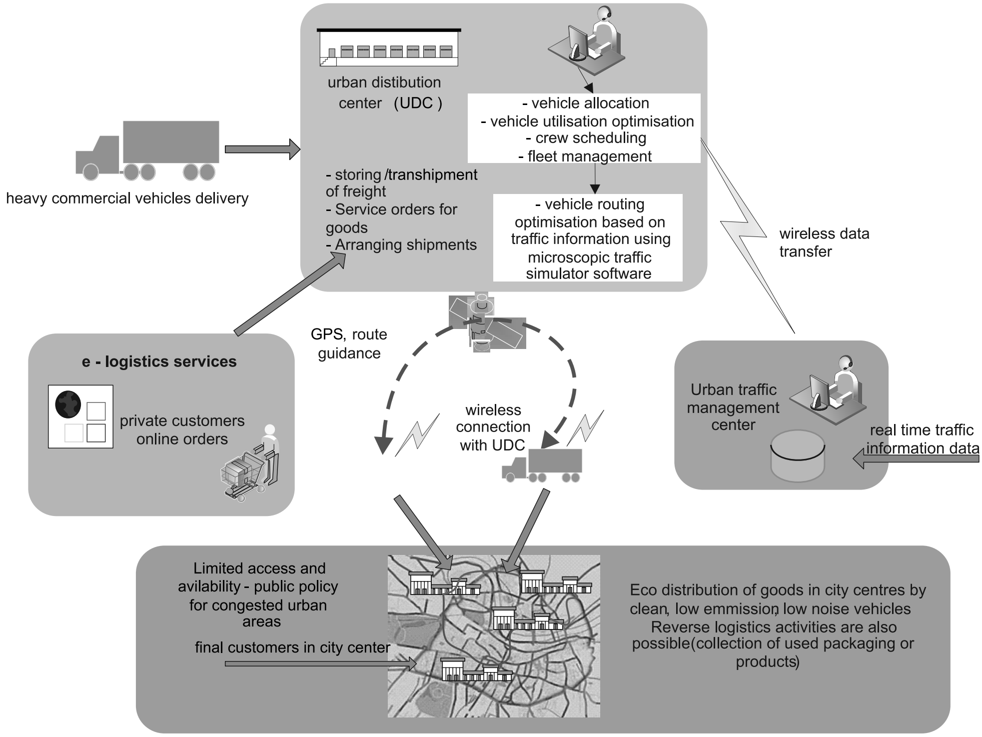

Fig. 7. Functional architecture of the proposed integrated sustainable freight transport system in urban areas

The result of the implementation of the presented approach to the transportation and distribution of goods in the city is a real opportunity to reduce the impact of unfavorable factors of transport for the immediate environment as well as a chance to limit operating costs and transport operators to increase the level and reliability of services.

4. Overview of the key solutions and projects in the field of integrated and sustainable urban freight transport

Social and environmental nuisances from increased freight traffic has gained special importance in practice. Evidenced by the wide range of initiatives in this area in recent years in many metropolitan areas in the world. J. Munuzuri in his work decides to distinguish basic categories of activities undertaken in this area. The most important of these include:

– **solutions for the infrastructure and coordination of traffic** (expansion, modernization and adaptation of existing infrastructure for the city logistics hubs to support the creation of combined transport),
– **solutions for optimal space management** (allocation of new land for logistical purposes, operations of loading or unloading),

– **solution in relation to the conditions of access** (entry and movement limitations of vehicles in the protected areas, the time limits in which vehicles are allowed to enter the zone).

The author draws special attention to the importance of combined actions and use of the benefits from different categories in achieving the desired objectives for an integrated and sustainable transport solution [10].

4.1. Solutions related to the management of urban areas accessibility

London – Low Emission Zone

In response to the deteriorating air quality due to high traffic, the city authorities in London decided to designate the zone of reduced emissions – LEZ. It is defined as a space into which permission to enter is given only to vehicles that meet the appropriate criteria and EURO emission standards. The main purpose of this solution is to reduce the area of impurities originating from the vehicle as well as promoting the use of environmentally-friendly vehicles. There is a daily charge for carriers whose vehicles do not meet the requirements, and move within the zones, or perform logistics operations. The restriction zone covers most of London and is specially marked. It includes trucks, vans, buses and light commercial vehicles entering the area. In order to control the emission criteria duty vehicles within the zone ANPR (Automatic Number Plate Reading) system is installed. It uses specialized cameras to monitor the area. The result of this project was a reduction in the total emissions of particulate matter (PM) of about 6.6% and a significant decrease in NO_x emission in 2012. In the restriction covered area, the forecasted drop of NO_x and PM emissions in 2012 amounted to 14 and 20% [15, 17].

Stockholm – vehicle tolls in the city center

Stockholm is the second city after London in which, after testing and the referendum decided to introduce a system of large-scale fees for vehicles traveling in the city center (private cars and vans). The main objective of the project started in 2006 was a global reduction in traffic and emissions. An important, element worth emphasizing is the cooperation and involvement of many stakeholders in the implementation of the system, including the Swedish Road Administration, local city government and IBM company responsible for providing technology. As in the case of LEZ in London, there is a camera system used to identify vehicles. The fee is made electronically. The current results of the system are the reduction of the overall level of traffic within the city by about 20% during peak hours and the reduction of travel time by 30%. There is a significant improvement in mobility and facilitation of the process of goods distribution [3].

Copenhagen – adjust availability of trucks in the city center

In the beginning of 2002, the Municipality of Copenhagen decided to implement a mandatory certification system for vehicles delivering goods within the city center. The aim of the project was to reduce the negative environmental impacts caused by the movement of goods in the center and at the same time making the narrow medieval streets of the city more accessible by increasing the capacity and reducing the number of delivery vehicles. The basis of the project was certified vehicles carrying logistics operations in the city center. Three types of certificates (green, yellow, red) were established. The green certificate as the main type of license which indicates permission to enter the center and perform unloading or loading in specially reserved areas for commercial vehicles with a capacity of 2.5 to 18 tons, and using in the three-month period, an average of at least 60% of load capacity. Yellow is an option for operators who cannot meet the requirements of a green certificate. Red is dedicated to those providers only occasionally coming to the center and is valid for 1 day. Analysis of the results showed an increase in capacity utilization of vehicles, and this type of system only slightly contributed to a reduction in the level of traffic within the city center [5].

4.2. Solutions related to the infrastructure

Nijmegen – urban goods consolidation center

In 2008, Nijmegen, due to the deteriorating air quality and enhancing the movement of goods within the city, an initiative for the creation of a goods consolidation center appeared. The owner and administrator of the center was a company that provided logistics services for retail stores in the city center. The consolidation center can be used by operators who have declared their willingness to participate in the project. The distribution center was located on the outskirts of the city, where consolidated goods from suppliers were transported to customers through the individual stores with smaller vehicles powered by natural gas. Thus, heavy commercial vehicles had no need to enter the city center. In addition to the supply of goods to the store, the distribution center also offered a collection of packaging, storage and the ability to deliver items to private customers. During just the first year of the project, about 100 retailers joined, which resulted in a decrease in the total number of truck kilometers and a shortening of travel time by 5%. The total number of stops (unloading, loading) by logistics vehicles decreased by 7%. According to reports, this type of initiative also had a positive impact on improving the living conditions in the city by reducing pollution from vehicles and limiting noise [12].

Paris, Amsterdam – multimodal transport system for the distribution of goods

In recent years, due to increasing problems of congestion, the distribution process in many European cities has become more inconvenient. This is why more and more often, the concept of multi-modal integrated freight transport in urban areas is subjected to testing and analysis. There are some examples of initiatives and projects which try to reduce the role of road transport in favour of rail transport. At the beginning of 2008 in Paris, one of the retailers, Monoprix, decided to enter the solution, which is based on a combination of road and rail transport modes. A key element of the solution is to consolidate the flow of goods in the two warehouses located on the outskirts of the city. Then, using the automatic transshipment, pallets with goods are directly loaded on to a specially designed cargo train, which uses the public railway infrastructure, brings them into the city to the transshipment hub, from which, goods are delivered to 90 Monoprix stores shops, with a smaller fleet of low-emission vehicles. A diagram of the system is shown in Fig. 8.

The adopted solution resulted in limiting the negative effects of the urban distribution of goods throughout the Paris region. The most important is the reduction of total truck distance traveled in Ile de France (700 000 km/year) which in turn helped in the saving of up to 70 000 liters of fuel and reducing CO_2 and NO_x emissions by 340.000 and 25 tones [1] respectively.

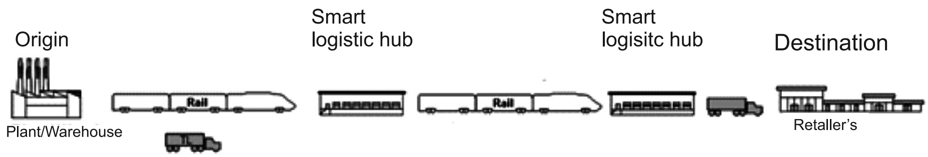

Fig. 8. Example of multimodal distribution system of goods retailer

A similar project in the use of rail transport as an alternative branch in the distribution of goods was carried out in Amsterdam in the period 2007–2008. The city had to replace about 2.500 to 5.000 vehicles entering the center every day by using special trams to carry the goods. On the outskirts of the city, where the tram lines end, special terminal nodes were prepared for handling the goods. Then, trams loaded with the goods travelled into the city, using four fixed routes to 15 points of transfer, where containers of goods were handled in small electrically powered vans and shipped to the stores (Fig. 9). A single tram was able to transport the amount of cargo comparable to that of four heavy goods vehicles with a capacity of 7.5 tones.

Fig. 9. Cargo tram project in Amsterdam [20]

Estimates of the project impact on the environment showed a reduction of particulate matters and nitrogen oxide by about 16%. Another element was the local noise reduction through the use of trams which are quieter than conventional vehicles [18].

4.3. Solutions for optimal space management

Barcelona – multi use lanes

In recent times, the urban space management in the context of goods distribution is becoming increasingly important. The fundamental objective in this case is the effective use of road infrastructure in urban areas, taking into account the specific needs of the distribution of goods. Road infrastructure management, in terms of time and space, was an issue for transport planners in Barcelona. In areas with intense traffic and large trade, in order to improve the availability and supply of goods, the municipal authorities decided to create additional lanes so called (multi use lanes) along the streets, dedicated to the appropriate groups of users over the time. Lanes are designed for ordinary vehicle traffic from 8–10 am. In the period between 10–17 pm, logistics operators can perform unloading of goods, and during the 17–21, loading operations. Then, till 8 am the next day, lanes can be used as a car park for local residents. These multi use lanes are specially marked with signs of VMS technology (Variable Message Signs), to display current information about the purpose of the lanes in the specified time. The second type of marking are bright lights that turn on when the lane is reserved for logistical operations. The main achievement of the implementation of the project was to reduce travel times for logistics operators by about 15% and bring about a significant improvement in operating conditions in these areas. Initiatives to improve the supply of goods in the area of effective space management have also been taken in other European cities such as Bordeaux, Aalborg and Bremen [19].

5. Summary

An integrated, sustainable system-wide approach to the transporting of goods in the urban area presented in this paper with a number of European projects and initiatives taking into account the assumptions of the concept, shown a strong current tendency to develop innovative ways to make the logistics and transport in Europe more environmental friendly. The working solutions are the response to the growing problems of congestion, goods movements, inefficiency of the goods distribution processes, the space deficit and the environmental and social nuisances in many cities. An important component of each of these solutions was an innovation, including the specificities of the city, use of modern technologies in the field of telecommunications, vehicle location, data processing and integration and also cooperation between many entities, developers and users of the system. Enhancing levels of urbanization, globalization and the consumption of goods are reflected in the growing demands on of logistics and transport activities. Therefore, further research and improvements in the integrated sustainable transport systems in urban areas are required to provide the expected benefits from businesses, public authorities and the local community.

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