The Analysis of Selected Issues of Signalling System Selection for a Railway Line with Set Railway Service and Traffic Parameters

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Summary

One of the essential elements of the railway transport modernization in Poland is the implementation of modern systems of interoperable ERTMS / ETCS (European Rail Traffic Management System / European Train Control System) fulfilling the tasks and functions of CCS (control-command and signalling) systems. The investment process including the implementation of ERTMS / ETCS requires prior development of a number of documents, which include feasibility study, terms of reference, a description of the contract and many others. The initiation of the investment process is preceded by a series of activities including the evaluation and selection of the right target railway traffic control system for the selected railway line. Due to the interoperability requirements, it becomes necessary to develop methods for assessment of the possible ERTMS / ETCS configurations and later selection of a configuration for a railway line with predefined service and traffic parameters. The aim of the publication is to present a concept that can be considered as the basis for methods of analysis and rail control traffic system selection. The sample line, which was selected to carry out research and analysis, is a section of the selected railway line section of the railway line No. 7 due to its strategic location and traffic load.

Keywords: system, rail traffic control, ERTMS/ETCS

1. Introduction

The genesis of the ERTMS / ETCS was the striving to develop a unified European rail transport system in order to achieve the expected quality and efficiency of rail services while maintaining traffic safety at the highest level. The ERTMS / ETCS is a modern system of rail traffic command, control and signalling, which also offers opportunities to select and adjust the version of the system for a railway line given set parameters of movement, in particular, this refers to the capacity or the consequences of trains. This raises the need to address the problem of selecting the ERTMS / ETCS for the specified line. The solution should lead to the development of the concept of a standardized method for selecting the ERTMS / ETCS, according to clear criteria, taking into account all possible aspects such as the cost of installing and maintaining the system, the impact on capacity and traffic flow and many others.

2. Brief description of the ERTMS / ETCS system

The functioning of the ERTMS / ETCS is a digital transmission of signals between devices installed in the track and devices installed in the rolling stock and between the rolling stock and the radio block centre (RBC). In the case of ETCS Level 1 balises teams communicate spot information to the traction vehicle on the location of the front of the train and the binding speed limit on the rail section – transmission between the railway track and the rolling stock. The system ERTMS / ETCS level 2 and ERTMS/ETCS level 3 (Fig. 1) is used to read information from the point balises on traction unit's location and two-way transmission of GSM-R transmitting to the RBC (radio block centre) information on the location and speed of the train in the direction of RBC train – electronic orders mandating driving the speed limit on the given length of permanent way [2, 4]. Due to the diversity of the ETCS 2 and 3 subsystems' concept in relation to ETCS 1 and applied GSM-R and RBCs, these subsystems belong to the ERTMS / ETCS class. Regardless of the ETCS level, the current train speed and the distance of the train path are continuously monitored at every ERTMS/ETCS level - on the traction vehicle (ETCS 1) and on the vehicle and the center of RBC (ETCS 2 and 3). This allows the calculation of the current dynamic profile at any given time train which is dependent on the speed limits resulting from the pro-

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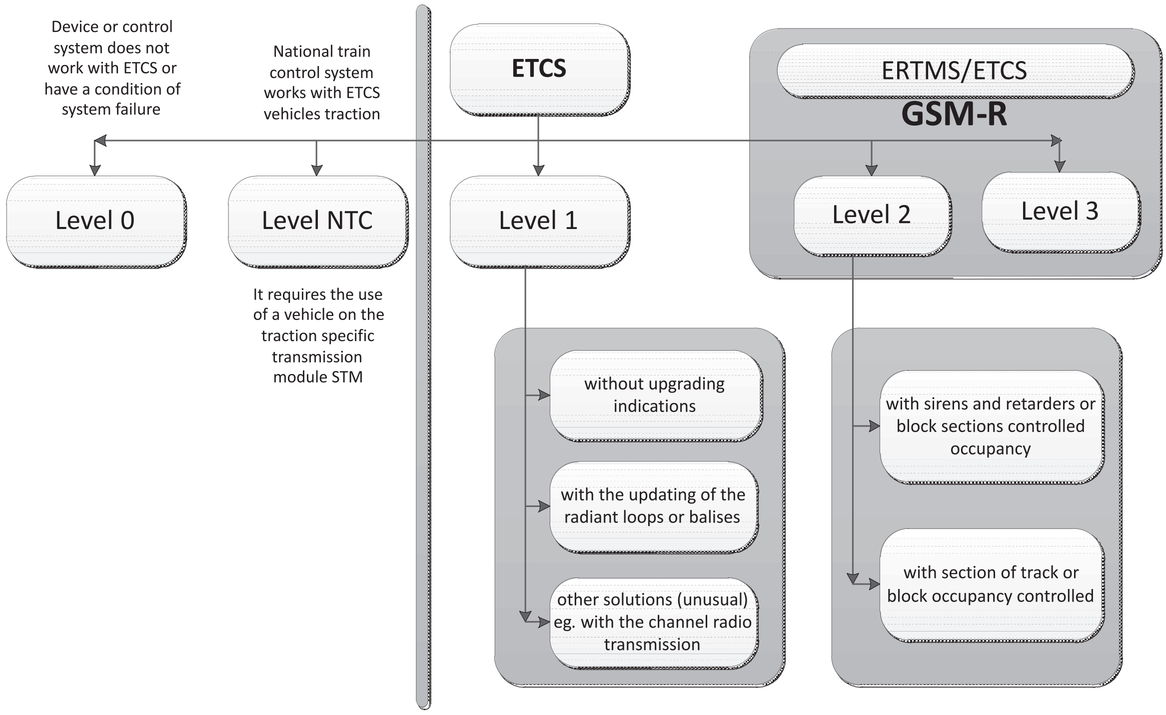

Fig. 1. Subsystems ERTMS / ETCS; Source: Own elaboration based on [1, 3, 7]

file of the static permanent way. The dynamic profile allows supervising the speed limit, and in case of the lack of driver's reaction it ensures safe braking. Possible ERTMS / ETCS configurations are shown in Fig. 1.

Analyzing the diversity of ERTMS/ETCS subsystems configurations and the requirements of the railway line on the required capacity allowed for different speed trains, investment and operating costs, and a number of other restrictions or assumptions, it becomes essential to select properly the subsystem or ERTMS / ETCS for a given railway line.

3. Some problems of Ertms / ETCS implementation

However, the problem formulated in earlier chapters of choosing the ETCS system due to the traffic assumption, would be incomplete if there were not also made the analysis of the possibility to equip traction vehicles with on-board ETCS subsystems, on the one hand the on-board ETCS „module" installed on board the locomotives and on the other hand, the implementation of permanent ETCS equipment subsystems. In practice, it is not impossible to equip at the same time all traction vehicles with ETCS subsystem whereas the modernized, and two traffic control systems must be maintained on the modernized line during migration This results in the inevitable necessity of simultaneous operation of existing control systems, along with a target ETCS on-board and / or in the terrain- area part of ETCS subsystem. The modernization, upgrade or extension of the line should not limit the movement of traction units equipped only with ETCS on a given line. Limiting line access to trains fitted with ETCS is considered economically unacceptable. Factors that must be taken into account during the ETCS subsystem selection and implementation can be determined as follows:

- the cost / benefit analysis resulting from the ETCS implementation , in the transition period, may be unfavorable and the importance of interoperability will not be effective,
- the optimal strategy provides that the modernization or upgrade project of the railway line should take into consideration the ETCS development and installation of the ETCS subsystem in traction vehicles,
- striving to achieve a coherent network of selected lines equipped with ETCS, e.g. interoperable international corridors and equipping sufficient number of traction vehicles with the ETCS system will allow reducing costs of control systems' migration [7].

4. Selection criteria for ERTMS / ETCS Solutions

The currently adopted on the railways guidelines for improving the safety and efficiency of train traffic control, having a significant impact on the tasks and operating parameters, assume the replacement of existing control equipment into ETCS subsystem or ERTMS system. However, due to the cost of investment and the volume of transport work it is not justified to implement these systems on all railway lines. The Impact Analyses of ETCS on the process of train control efficiency (led by UIC – International Union of Railways) [15] showed clearly that the implementation of ETCS, especially ETCS level 1 and level 2, does not significantly improve the capacity of the railway line (in the case of ETCS level 1 configuration without infill it even lowers the railway line capacity). Analyzing the above systems' properties a question can be raised: how to develop a method on the basis of various information, parameters and assessment to select accurately ERTMS / ETCS configurations for a specific railway line taking into consideration the indicated assumptions.

It seems that the desire to develop a method of selection, taking into account many factors can lead to clear conclusions concerning the selection. Nevertheless, the indication would require conducting tests because it may turn out that there are factors of apparent influence on the choice of the system and these factors can been omitted for the purpose of analysis. However, notwithstanding the above conclusion, the multiple-criteria analysis method is proposed as it allows indicating a proper ETCS / ERTMS system before the investment process begins. Multi-criteria analysis could be based on qualitative and analytical conclusions including such factors as:

1) technical and traffic characteristics, as well as operating conditions of the line on which the system installation is intended,
2) ERTMS / ETCS properties,
3) the rules for the implementation of the investment process,
4) the analysis of the development costs and the potential costs of maintaining the ERTMS / ETCS system,
5) of the assessment of risk analysis of the investment and safety; Regulations No. 402/2013 [11].

These factors should be correlated with the objectives of the multi-criteria assessment (Table 1). The conclusions resulting from this analysis will be a priority while choosing an ERTMS / ETCS configuration.

Table 1

Basic parameters of the section of the selected railway line Source: Own elaboration basic on [8]

Basic parameters	Value
Length of the analyzed section of the railway line [km]	147,404
Capacity	220
Average speed of passenger trains [km/h]	93
Average speed of freight trains [km/h]	68
The maximum axle load [kN]	221
The minimum interval between trains [min]	6,5

Source: Own elaboration basic on [8]

5. Concept of assessment and selection method of ERTMS / ETCS solutions on the selected line

The analysis of multi-criteria selection of ETCS and ERTMS / ETCS system is a series of further actions arising from the adopted method. This method refers to the identification of targets and determining the criteria for measuring the degree of achievement of these objectives. After defining the objectives, criteria and determining their significance there are determined evaluations of individual variants of the infrastructure investments advancement with regard to the criteria identified in the individual targets. The goal is to be able to measure specified quality assessment criteria of configurations.

Another important issue in assessing particular variants due to the adopted criteria is to normalize variants ratings [6]. The variant evaluation set for each criterion may be expressed in different units and may involve both maximized criteria (the greatest value is the best) and minimized ones (the lowest value is the most advantageous). The aim of standardization is to meet the comparability requirements. Having conducted the assessment of particular variants, relying on the so-called point method, aggregate indicators can be determined for the assessment of particular upgrade or repair variants or other investment tasks on the analyzed railway line.

In order to calculate the indicators of individual goals the products of the weights of criteria with assigned weights for each variant are summed up. In order to calculate the final indicators, which will allow determining which option is the most beneficial, the products of the weights of each of the goals of the indicator, which has been obtained for each goal, should be summed up. The variant, which reached the highest indicator (the closest value of 1) is most preferred [5, 6]. The advantage of this method is its clarity and explicitness. Railway line No. 7 was selected as the object of an exemplary multi-criteria analysis. Factors such as intuition and expertise are also significant in this method, as they allow determining the importance of the specific goals and criteria. Further steps are carried out according to a precise calculation procedure. The proposed method of multi-criteria analysis can be a basis or a guideline to select the variant of the investment project. In order to perform a multi-criteria assessment according to the proposed method, three main objectives were identified, which, together with their determined weights are listed in Table 1.

Table 2

Objectives and criteria of multi-criteria valuation and their weights

Name of goals (groups of criteria)	Weight [%]
Economic	45
General social	30
Environmental	25

[Source: Own elaboration]

To compare the different of ETCS and ERTMS / ETCS variants criteria corresponding to the selected goals were defined and their weight was identified:

1. Economic goal:
   - the level of investment – 0.3,
   - the level of operating costs – 0.4,
   - the volume of operational work in train per kilometer – 0.3.
2. Social goal:
   - safety – 0.3,
   - the impact of modernization on regional development – 0.2,
   - the ease of the project implementation – 0.1,
   - the reduction of travel time – 0.2,
   - the behavior of line capacity and the level of freedom of movement – 0.2.
3. Environmental goal:
   - reduction of external costs through the takeover of passengers from road transport – 0.3,
   - the noise reduction – 0.1,
   - the decrease in the number of accidents involving animals – 0.2,
   - the degree of impact on protected areas – 0.3,
   - the occupancy of the area – 0.1.

After determining the goals, criteria and their significance, the assessments of the investment accomplishment were established for different variants of a train control system for the railway line under consideration depending on determined criteria. Values of criteria weights were selected on the basis of the analysis of information concerning the properties of the ETCS and ERTMS / ETCS systems types, which could be considered as objects of investment, to be built on the railway line under consideration. One of possible tools to determine the assessment criteria values is the SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis referring to the specifications of the strengths and weaknesses of the investment as well as opportunities and threats related to the built-in ETCS system on the line depending on the level of the installed system. Variants of train control system possible to be built on the line under consideration are determined as follows:

- Variant 1 – ETCS system (level 1) without infill of the information on the permitted speed indicated on the semaphore, to which a train is approaching on a block apart,
- Variant 2 – ETCS system (level 1) with preceded update of information about the permitted speed on a semaphore, to which a train is approaching,
- Variant 3 – the system ERTM / ETCS Level 2 with built-existing traffic lights.

SWOT analysis [8] was conducted for the variants. This analysis can be used as a complement to multi-criteria analysis [12]. In [8], the assessment of the cost of installing systems selected for the possible construction of the railway line was carried out. In the railway industry, the RAMS method is also often used for risk assessment [13, 14] but this method is not included in the study.

The results of multi-criteria analysis were presented in Tables 3, 4 and 5, which in respect of the proposed variants, represent respectively the multi-

Table 3

Multi-criteria assessment

No.	Criterion		Assessment of options			The search for extreme
	Name	Weights	Variant 1	Variant 2	Variant 3	
1	**Investment expenditures**	0.3	1.00	0.80	0.50	max
	Operating costs	0.4	1.00	0.90	0.60	max
	Operation work	0.3	0.85	0.93	1.00	max
2	**Safety**	0.3	0.85	0.90	1.00	max
	Regional development	0.2	0.90	0.92	1.00	max
	Ease of project implementation	0.1	1.00	0.95	0.85	max
	Reduction of travel time	0.2	0.70	0.85	1.00	max
	Capacity of the line	0.2	0.65	0.90	1.00	max
3	**Reduction of external costs**	0.3	0.80	0.85	1.00	max
	Noise reduction	0.1	0.87	0.92	1.00	max
	Decrease in accidents involving animals	0.2	1.00	1.00	1.00	max
	Impact on protected areas	0.3	1.00	1.00	1.00	min
	Occupancy of land	0.1	1.00	0.98	0.95	min

[Source: Own elaboration]

Table 4

The values of standardized variants assessment according to the criteria and objectives of the modernization of the railway line

No.	Criterion		Standardised assessment of options		
	Name	Weights	Variant 1	Variant 2	Variant 3
1	**Investment expenditures**	0.3	1.00	0.88	0.50
	Operating costs	0.4	1.00	0.95	0.60
	Operation work	0.3	0.85	0.93	1.00
	Score	**1.0**	**0.95**	**0.92**	**0.69**
2	**Safety**	0.3	0.85	0.90	1.00
	Regional development	0.2	0.90	0.92	1.00
	Ease of project implementation	0.1	1.00	0.95	0.85
	Reduction of travel time	0.2	0.70	0.85	1.00
	Capacity of the line	0.2	0.65	0.90	1.00
	Score	**1.0**	**0.80**	**0.90**	**0.98**
3	**Reduction of external costs**	0.3	0.80	0.85	1.00
	Noise reduction	0.1	0.87	0.92	1.00
	Decrease in accidents involving animals	0.2	1.00	1.00	1.00
	Impact on protected areas	0.3	1.00	1.00	1.00
	Occupancy of land	0.1	1.00	0.98	0.95
	Score	**1.0**	**0.93**	**0.94**	**0.99**

[Source: Own elaboration]

criteria assessments values, standardized assessments values and the results of the of multi-criteria evaluation of modernization.

Based on the results presented in tables 3 and 4, table No. 5 was prepared. This approach is well illustrated by the example of the analysis of CCS system selection. More information on the analysis of the selection has been presented in [8].

Table 5

The results of multi-criteria evaluation of options modernization of the railway line No. 7

Goal		Standardized assessment of variants		
Name	Weights	Variant 1	Variant 2	Variant 3
Economic	0.45	0.95	0.92	0.69
Social	0.30	0.80	0.90	0.98
Environmental	0.25	0.93	0.94	0.99
Score	**1.0**	**0.90**	**0,92**	**0.85**

[Source: Own elaboration]

The results of the analysis unquestionably show that the preferred option is Option 2, that is the modernization of incorporating the installation of ERTMS / ETCS Level 1 configuration without infill. The selected system does not reduce the capacity and the costs of installation are not the greatest (Tab. 4). In order to compare the results, Table No. 6 was presented, which contains the approximate comparative performance data of lines that support the selection of the control system variant.

Table 6

Comparison of the section of the selected railway line, taking into account variations modernization

Parameter	Now	Variant 1	Variant 2	Variant 3
Capacity	220	max 450	max 480	max 578
Average speed of passenger trains [km/h]	93	140	160	200
Average speed of freight trains [km/h]	68	100	120	160
The maximum axle load [kN/axle]	221	221	221	221
The minimum interval between trains [min]	6.5	4	3	2.5

[Source: Own elaboration]

The example illustrating the method of multi-criteria analysis does not exhaust the problem of the method of the control system selection. The development of a full standardized method should also take into account other issues such as the method for evaluating investment risk, line capacity, the selection of the length of the block spacing depending on the specifics of the anticipated traffic and others. The preliminary assessment of investment risk carried out in [9] also indicates the selection of ETCS Level 1 configuration without infill.

6. Conclusions

The search for standardized methods for the selection of solutions for rail transport includes not only the issues of selection and evaluation of CCS (control-command and signalling) systems to adapt to the Polish conditions, but to develop integrated multi-problem-oriented IT environments [9]. The qualitative methods such as the SWOT analysis or the matrix of risks may be a complement to the presented multi-criteria assessment method. The modernization process starting from the tender documentation to obtaining EC certificates and placing into service is a complex process and the use of objectified methods standardizing accurate solutions supporting investment will be important to reduce the time of new control systems and automation implementation in railway transport.

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