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***Theoretical Principles
for Quantitative Evaluation
of Railway Interoperability***

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PRELIMINARIES OF THE RESEARCH

This dissertation focuses on interoperability, namely the key technical element of this structural change.

Interoperability was defined in European legislation as a necessary tool for opening the rail transport market. The political objective is to establish a Trans-European Transport network, which enable citizens and economic organisations to benefit the European area without frontiers. This requires a new technical regulatory framework, especially the existing UIC leaflets, based on agreement between railway companies, has to be converted into compulsory European legislation and extended to cover all of the railway subsystems.

It is important to follow the consequences of the political decisions, therefore the European legislations generally defines an obligation for the European executive organisation to monitor the progress made towards achieving the goals defined. This obligation has been met in case of railway interoperability too with addition a tool shall be developed to provide a chart of the interoperability level of the trans-European rail system.

The first monitoring activity representing European interest was the **Rail Market Monitoring Scheme**. The study proposed a data collection system and a special evaluation method [Giv01]. The implementation and the result of this tool will be presented in detail in the chapter benchmarking.

The progress in interoperability was assessed by some dedicated study. One of the first was the **Study of the Implementation of Directive 96/48/EC** in 2002 [Gra02]. The author was Michael Schönberger.

The document summarised the interoperability progress across the EU 15 member states on the high speed lines. The evaluation based largely in text form evaluation, but some technical parameters were collected and analysed.

Dr. Christian Kirchner presented a popular and demonstrative solution in 2002: the **Rail Liberalisation Index** [Ibm02], [Ibm04].

This study was initiated by the German Railway (DB) and aims to represent a classification of European countries according to the situation of their railway market development in the way to the liberalisation. To this end, the authors have developed an universal index which represent the absolute level of liberalisation achieved. The high the value of this index the open the railway market in the country is.

This index is quite simple and demonstrative therefore as such gave a new objective for present research: to develop a similar index informing about the level of interoperability achieved.

The only dedicated benchmark research in the railway subject was the **BOB Railway Case: Benchmarking Passenger Transport in Railways** [Nea03], managed by NEA Netherlands.

The paper started with an institutional analysis as a compulsory subject of numerous European studies. The consortium partners selected the service quality as most important and actual issue. Amongst the different quality parameters first the analysis of punctuality was decided. However some traditional statistics exist in all involved countries, the conduct of benchmark proved very difficult as the definition of delay was different from country by country.

One other important study giving very valuable benchmarks was the **Study of the financing of and public budget contributions to railways** [Ner04]. The assessment proved very informative not only from budgetary perspective, but to understand the sophisticated relationship between member states and railway companies and the functioning of the railway system. Although, the subject has less importance to interoperability, the study gives practical background information.

The latest study has analysed **The implementation of the EU Directives 2001/12, 2001/13 and 2001/14 in the Member States** in 2006 [Ste06]. This directives was part of the so called “First railway package” and significantly determined the structural changes. The thematic of the study was - similarly to the previous ones – to analyse the situation country by country on the basis of statistics and shareholders’ view.

OBJECTIVES OF THE PHD THESES

The present thesis aims to propose an appropriate monitoring tool to evaluate the development of interoperability.

However it is no doubt that many traditional indicators could be found, there is a high risk that these will not give a right evaluation about the results achieved. The author’s experience suggests that the railway system is so complex that a simple statistical data could not asses the technical interoperability of the system. These concerns will be discussed in details in the introductory section of this dissertation.

Consequently a new methodology is necessary to define the right procedure of monitoring. This needs a detailed research activity taking into account the political aims, the limits of the present legislative and institutional system, the existing benchmarks, the available innovative methods and the information technology.

The objective of the research is to offer a new, simple and effective method to evaluate the progress of interoperability achieved. It would help to better understand and evaluate the

technical compatibility of the European Railway system and support further political decisions.

Unfortunately the Agency did not recognise the importance of a strong theoretical background, consequently the necessary study carried out on the basis of the author's individual ambitions and resources. Although the experience gained from the work in ERA was vital to perform this research and draft the thesis in good quality.

The research contained the following main activities:

- Analyse the legal structure, the political objectives and the specific railway operating rules to determine the target parameters,
- Collect the research history in the similar subjects, perform benchmarks within the railway sectors and in other sectors, analyse the existing literature,
- Develop a simple and effective method to simulate the interaction between the railway subsystems and indicate the progress in interoperability,
- List the existing and planned information sources; evaluate them with regard of relevance, accessibility and accuracy.
- Consider the assessment of interoperability, crosscheck the requirements and the technical possibilities, listing the basic parameters from different legal documents,
- Analyse the parameters, compare with current operational exercise, select the critical values, adopt them to the simulation method,
- Verification of the model,
- Disseminate the results by publication.

The method resulted by this research is in line with requirements from the European legislation therefore it is eventually applicable to support the monitoring of interoperability on the request of the EU.

METHODOLOGICAL BACKGROUND

Monitoring could be based on different evaluation tools as follows:

Statistical indicators could be calculated on the basis of information received from the sector and available in different databases and registers. These indicators give an overview of the sector activity related to interoperability requirements, but do not reflect the effectiveness of the measures taken.

The technical compatibility between the subsystems can be demonstrated by simulation. The present thesis aims to define a model on the basis of scientific considerations. The objective of the model is to give an indicator about the railway interoperability on a chosen region or

on a whole Trans European Network, taking into account especially the technical compatibility of different subsystems.

The mathematical approach of the model: there is a network which was aggregated from individual sections with given parameters and there are vehicles operating on the network, which also have technical parameters. Some network parameters exclude the operation of vehicles with a given parameters. The high the level of interoperability the less excluded pairing exist.

The results will reflect the achievement of the political aim at interoperability and the potential of cross-border railway traffic. As far as this simulation is not only based on facts and exact information but also on assumptions and empirical processes, the results will be more general and cannot be considered as the basis of any legal or economical consequences.

The general tendencies and non-quantifiable factors can be summarised in the overall evaluation giving, an overview (in free text form) of the interoperability issues in the sector.

NEW SCIENTIFIC RESULTS

1. I have identified a legal, technical and theoretical framework for a monitoring activity adapted to the limitations and opportunities inside the European Community.

a) I have defined the theoretical principles of monitoring. This activity needed analyse of the legal background, of the conformity certification procedure and benchmarks from other transport sectors.

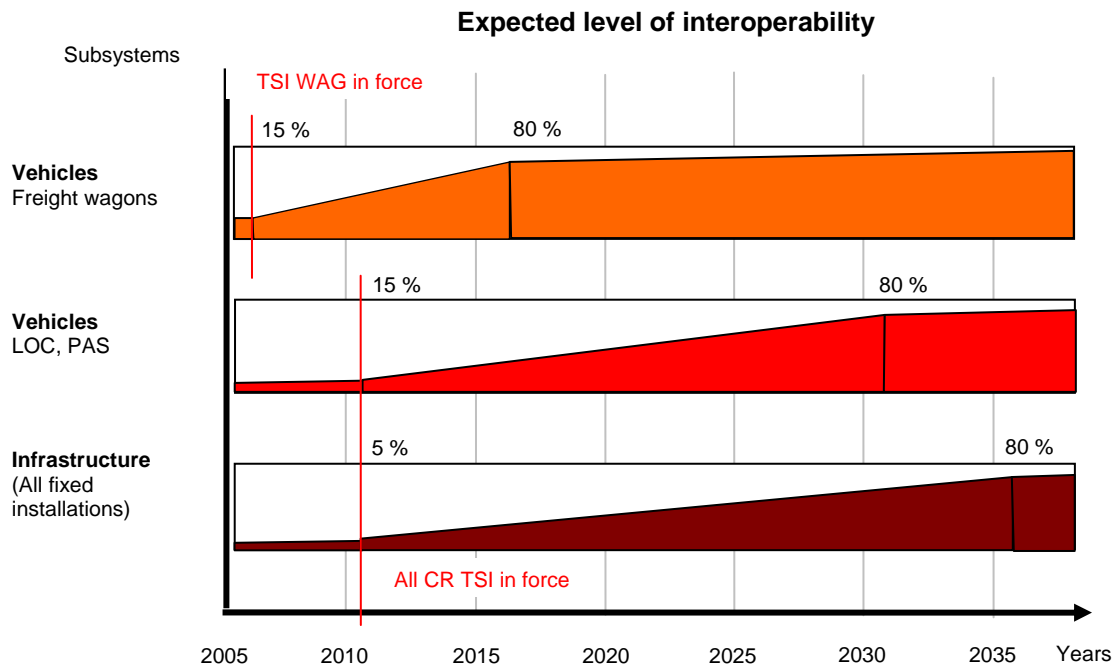
The regulatory framework of the railway interoperability is in the middle of a structural change. Procedures are defined in different legal text and responsibilities are dedicated to different authorities, technical investigation bodies and professional organisations. Therefore a complex understanding had to be established about the principles of monitoring activity.

The appropriate benchmark is always important to understand what are the core benefit of the process, to learn about best practice from others and to ease our work if comparable solutions are already available [1] [5]. For the monitoring system as a whole, no comparable solutions was found from transport sector, although some indicators used by European Commission in inland waterway and road transport could be adopted for the railway interoperability. Moreover the selection of indicators may follow the principles introduced for road safety.

b) I have identified the information sources and presented a forecast for its availability. It was needed to list the available information sources even those projected in the different legislation documents. Only few of them are only available, most of it is under development. The progress of the works and sector discussions about further developments give the possibility to make a forecast about their availability.

As many of the interoperability database are in the project preparation phase, it was necessary to list the available information sources even those only projected in the different legislation documents. Only few of them are already available, most of it is under development.

As the present thesis aims developing a simulation method based on statistical calculation, the model can work only if statistically sufficient number of interoperable subsystems is already in operation. The progress of the works and sector discussions about further developments gives the opportunity to present a forecast about the availability of three major group of subsystems [3] [4]. The forecast based on the lifecycle of each subsystem.



2. I have defined a comprehensive technical requirement system based on common specification and taking into account the implementation limitations.

a) I have established a complete list of basic parameters from TSI for Conventional Rail System. As the development of conventional rail TSI are in a different phase, my dissertation is the first trial to summarise the requirements from all TSI in one common document. However it should be noticed, that this list is only iteration until the latest TSI will be published officially.

The basic parameters were collected on the basis of what system component of the railway system it concerns, i.e. fixed infrastructure, vehicle or operation. (This classification is not identical with the subsystems since for instance the TSI “Safety in Railway Tunnels” contains requirements both for vehicles, infrastructure and operation.) It was also categorised according the different possible type of requirements:

- F – Fixed requirement,
- X – Cross reference to other TSI,
- FX – Fixed requirement in a referenced standard,
- M – Requirement defining a maximum limit value,
- P – Choice between possible parameters
 - Pro – Choice between standard profiles or value ranges
 - Cat – Value in function of other technical parameters
 - Ch – Free choice of value
- O – Open point (definitive),
- OT – Open point (at the time of drafting the thesis)

b) I have identified the parameters which potentially limit the interoperability.

Some basic parameters were defined allowing choice between technical solutions. . The choice can have effect for the interfaces and therefore limit the accessibility even for subsystems declared as interoperable. This parameters were marked with “P” during analyse presented in the previous chapter and defined as critical. The choice of different technical values can have effect for the interfaces and therefore limit the accessibility even for subsystems declared as interoperable. In total 37 such parameter were found.

With a further analyse some of the parameters could have been sorted out from the list, because some operational measures could ensure the compatibility with requirements and finally the access of vehicles to sections investigated. These parameters were indicated as non restrictive while the remaining 19 represents a real limitation. The table below presents the number of critical parameters according to different TSIs [6] [7].

Identified critical parameters

TSI	Parameter with choice	Restrictive	Non restrictive
INF	8	3	5
ENE	3	1	2
CCS	4	4	-
SRT	1	1	-
PRM	3	2	1
RST PAS and LOC	12	5	7
RST WAG	5	2	3
Total	37	19	18

3. **I have defined a new simulation method based on the EC conformity and additional individual technical features of the subsystems.** So far the interoperability between infrastructure and vehicles is depending not only on the individual conformity of both system components, a simulation method has been developed for cross-checking the accessibility. This allows quantitative evaluation of the interoperability level based on real ability of the vehicles to circulate on the European Railway Network.

The compatibility check of interface requirement was generated as vector multiplication for each "i" basic parameter:

$$rx_i = \mathbf{in}_i \times \mathbf{CM}_i \times \mathbf{ve}_i$$

Where the infrastructure vector $\mathbf{in}_i \mid in_{i1}, in_{i2}, \dots, in_{in} \mid$ is a unit vector, each of its coordinates match the compliance with one possible choice of that parameter. Analogically, the vehicle parameter vector $\mathbf{ve}_i \mid ve_{i1}, ve_{i2}, \dots, ve_{im} \mid$ has the same

The compatibility matrix $\mathbf{CM}_i [n,m]$ is also a unit matrix, each of its element corresponds a pairing of infrastructure and vehicle parameters, its value defines that the given pairing is allowed or not.

The result is a scalar rx_i . If $rx_i = 0$, the two system components are not compatible regarding the requirement involved. If $rx_i > 0$ for all "i" parameter, the infrastructure section is accessible for the vehicle and interoperability is ensured.

This result will then be registered into the result matrix:

$$\mathbf{RM} [x,y]$$

Where:

- x is the identification number of infrastructure sections investigated and
- y is the identification number of vehicle type investigated.

The value of each element of the matrix $rm_{x,y}$ is:

- 1 – if the infrastructure section is compatible with the vehicle type.
- 0 – by default, that means not compatible or not investigated yet.

The last step to evaluate the overall interoperability is then to calculate the average over the values in the matrix and present the result in percentage format:

$$IOP [\%] = 100 \cdot \frac{\sum rm_{x,y}}{x \cdot y}$$

This allows quantitative evaluation of the interoperability level based on real ability of the vehicles to circulate on the European Railway Network, therefore to monitor the real political aim of the interoperability [2] [3]. I have demonstrated the suitability of this method with a simulation example, presented in Chapter 10 of my dissertation.

To perform the whole calculation, it is necessary to transform the basic parameters in the required format as defined in the following chapter.

4. I have redefined the content and allocated a clear value range to some basic parameters in order to be suitable for the calculation.

Definition of multi-dimension unit vectors were simply possible for most of the parameters since the choice of technical characteristic is limited to standard values or to a limited number of existing solutions. Although three of basic parameters allowed a wide choice of technical solutions or values which would make the calculation complicated and difficult, even impossible. Three of basic parameters allowed a wide choice of technical solutions / values which would make the calculation complicated and difficult, even impossible. To allow its application and make the calculation faster, some simplification was made and an appropriate parameterisation was performed regarding to these three parameters.

A compatibility matrix CM_i had to be defined when both infrastructure and vehicle components have a similar choice between values/solutions. In this case, the technical compatibility depends on the possible compatibility of parameter pairing. 15 interface matrixes have to be defined in total. The format of the matrix is:

$$CM_i [n,m]$$

Where:

- i is the identification of the parameter involved,
- n is the number of possible values of the infrastructure vector and
- m is the number of possible values of the vehicle vector.

The value of each element of the matrix $cm_{x,y}$ is:

- 1 – if the combination ie_{ix} and ve_{iy} is permitted
- 0 – if the combination is not permitted.

As some of the requirements shall be applied only for specific subsystems, the parameter vectors were split into modules. Then the calculation can only use the suitable modules according the character of the subsystems.

MO – Requirements for all combination of system elements

MA – Additional requirements for freight wagons

MB – Additional requirements for traction

MC – Additional requirements for electric traction

MD – Additional requirements for vehicles with driver cab

ME – Additional requirements for passenger transport

5. I have defined a validation method proving the correctness and relevance of the simulation.

It helps to understand whether the problem raised in the present dissertation, namely the potential additional technical barriers originated from free choice of solution, represents a real concern, and give an approximate value about the seriousness of this issue.

The validation is based on the correlation analysis and uses a new approach, comparing some basic parameter of one subsystem with results of the simulation related to other subsystem. The basis of the comparison is:

- from one part the existence of the EC conformity certificate of one subsystem (this certifies that the subsystem fulfils the TSI requirements)
- from other part the number of positive answers from the result matrix (the real accessibility of the subsystem regarding the interfaces).

Then the correlations between conformity and real accessibility of infrastructure sections can be defined using the well known correlation equation:

$$r_{in_x, pa_{sx}} = \frac{\sum_{i=1}^n (in_i - \bar{in}_x)(pa_{si} - \bar{pa}_{sx})}{\sqrt{\sum_{i=1}^n (in_i - \bar{in}_x)^2 \sum_{i=1}^n (pa_{si} - \bar{pa}_{sx})^2}}$$

Similarly the correlations between conformity and real accessibility of vehicle types can be defined as follows:

$$r_{ve_y, pa_{ty}} = \frac{\sum_{j=1}^m (ve_j - \bar{ve}_y)(pa_{tj} - \bar{pa}_{ty})}{\sqrt{\sum_{j=1}^m (ve_j - \bar{ve}_y)^2 \sum_{j=1}^m (pa_{tj} - \bar{pa}_{ty})^2}}$$

It is expected a result higher than 0.6 which will prove a strong link between the EC conformity and accessibility, practically the EC conform vehicles are accessible for more infrastructure section than the vehicles without. If the value was lower than 0.6 it would mean that there is no correlation between the conformity and the accessibility. This result would prove that the problem of free choice of some technical values is more serious that it was supposed in the introductory section of the dissertation, the system of the conformity assessment will not reach the political objectives. [7]

LIST OF PUBLICATIONS

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