



UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Logistics and Transport Management

Rail Quality Based Index

Shengda Zhu and Linkai Wang

Supervisor: Prof. Rickard Bergqvist

June 2015

Abstract

The aim of this thesis is to establish an integrated rail quality based index to evaluate different freight wagons' performance. All materials are collected through literature reviews and interviews. The Rail Quality Based Index (RQBI) is established in the form of cost that can represent the main quality aspects associated with freight wagons self-characteristics. The index construction includes four main components, i.e. infrastructure, energy, maintenance and noise. Each component's cost can be calculated by applying different methods from previous studies. By comparing index value with benchmark, the RQBI can help different parties in rail freight industry to evaluate and compare their freight wagons quality performance. This research concludes costs differentiated by wagons' characteristics and tries to represent them in an integrated index's form. Though, due to data deficiency, validation of the index and establishment of relevant benchmarks are not fully discussed in this research, it helps to further understand quality evaluation of freight wagons and points out a new perspective of future relevant researches.

Key Words: Rail Freight Quality; Wagon; Benchmarking; RQBI; Differentiated Infrastructure Charges.

Acknowledgements

We would like to thank all those who have given support during the completion of the thesis. Firstly, we want to express our deepest gratitude to our supervisor Professor Rickard Bergqvist for all the guidance, advice and comments during the process of the thesis. Secondly, we appreciate all respondents who participated in the interviews and we are grateful for their quick responses, expertise and helpful suggestions. Finally, we would like to thank our families and friends for the love, support and encouragement.

Best Regards
Gothenburg, June 2015.

Shengda Zhu

Linkai Wang

Table of Contents

Abstract	I
Acknowledgements	III
Table of Contents	V
List of Figures	IX
List of Tables.....	XI
List of Abbreviations.....	XIII
<u>1 INTRODUCTION</u>	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Research Purpose	2
1.4 Research Question.....	2
1.5 Delimitation	3
<u>2 METHODOLOGY</u>	5
2.1 Research Strategy	5
2.1.1 Research Paradigm.....	5
2.1.2 Research Approach	6
2.2 Research Design	6
2.3 Data	7
2.3.1 Data Availability	7
2.3.2 Data Collection.....	8
2.4 Research Quality	9
2.4.1 Reliability	9
2.4.2 Validity	10
<u>3 THEORETICAL FRAMEWORK</u>	11
3.1 Background of Rail Transport	11
3.1.1 UIC Classification.....	13
3.1.2 FORD System	15
3.2 Rail Quality	16
3.2.1 Rolling Stocks Quality.....	16
3.2.2 Track Quality	18
3.2.3 Externality	19
3.3 Infrastructure Charges in Europe	21
3.3.1 Charging Types	21
3.3.2 Charging Philosophy	21
3.3.3 Charging Concepts	21
3.3.4 Charging Variables & Variable Categories.....	22
3.4 Benchmark.....	24
3.4.1 Benchmarking	24

3.5 Composite Index.....	26
3.5.1 Composite Indexing	27
3.5.2 Indexes in Transport Research	29
3.6 Bonus-malus System.....	32
3.7 Conclusion	32
<u>4 COST CALCULATIONS.....</u>	35
4.1 Infrastructure Cost.....	35
4.1.1 Damages	35
4.1.2 Practice in Sweden.....	38
4.2 Energy Cost	38
4.2.1 Resistance Forces.....	39
4.2.2 Practice in Sweden.....	43
4.3 Maintenance.....	43
4.3.1 Life Cycle Cost	44
4.3.2 Practice in SweMaint	46
4.4 Noise Cost.....	46
4.4.1 Short Run Marginal Cost (SRMC)	47
4.4.2 Noise Indicators	48
4.4.3 NDTAC	49
4.4.4 Practice of NDTAC in Europe.....	51
<u>5 INDEX CONSTRUCTION.....</u>	53
5.1 Assumption.....	53
5.2 Variables and Abbreviation.....	54
5.3 Rail Quality Based Index	55
5.4 Index Components	55
5.4.1 Infrastructure Cost	55
5.4.2 Energy Cost	56
5.4.3 Maintenance Cost.....	56
5.4.4 Noise Cost	57
<u>6 IMPLEMENTATION.....</u>	59
6.1 Implementation Proposal	59
6.2 Calculation Example	60
6.2.1 Assumptions and Input Data.....	60
6.2.2 Calculation and Revision.....	61
6.2.3 Application of a Bonus-malus System.....	62
<u>7 DISCUSSION.....</u>	65
7.1 Index Feature	65
7.2 Limitation.....	65
<u>8 CONCLUSION.....</u>	67
8.1 Future Research	67
References.....	69
Appendix	73

List of Figures

Figure 1. Research Design Steps	7
Figure 2. Boxcar 70 ton 50 feet	12
Figure 3. Gondola Car.....	13
Figure 4. Bogie Structure	13
Figure 5. Rolling Stocks Maintenance Procedure.....	18
Figure 6. Structure of rail track.....	18
Figure 7. Benchmarking Types	25
Figure 8. Procedure of Benchmarking	26
Figure 9. Crack Damage and Wear Damage in AEA model.....	37
Figure 10. Implementation Procedures. Source: Authors	60

List of Tables

Table 1. Interview guide	9
Table 2. UIC classification of locomotives axle arrangements.	14
Table 3. UIC classification of goods wagons	14
Table 4. TSI Noise Emission Ceilings for Freight Wagons.....	20
Table 5. Benchmark Types	25
Table 6. Track Charge of Freight Traffic.....	38
Table 7. Main Characteristics of Design Options.....	50
Table 8. Variables and Abbreviations.	54
Table 9. Specifications of S-category wagons.....	61
Table 10. RQBI and Benchmark indexes of S-category wagons	61
Table 11. Specifications of S-category wagons (Revised)	62
Table 12. RQBI and Benchmark indexes of S-category wagons (Revised).....	62

List of Abbreviations

AHP: Analytical Hierarchy Process
CFA: Confirmatory Factor Analysis
CSI: Clean Ship Index
EC: European Commission
EEDI: Energy Efficiency Design Index
EU: European Union
GBN: Global Benchmark Network
GHGs: Green House Gases
ICCT: International Council on Clean Transportation
IM: Infrastructure Manager
IMO: International Maritime Organization
LCC: Life Cycle Cost
NBSC: National Bureau of Statistics of China
NDTAC: Noise Differentiated Track Access Charge
POEI: Port Operator Efficiency Index
RQBI: Rail Quality Based Index
RU: Railway Undertaking
TSI: Technical Specification for Interoperability
TTCI: Transportation Technology Center Inc.
UIC: International Union of Railways
WOs/WKs: Wagon Owners/ Wagon Keepers

1 INTRODUCTION

1.1 Background

Since the advent of the first train in the early 19th century, railway has been a time-honored freight transport option and experienced many challenges and innovations. In the past decade, rail transport volume increased in many places in the world and is believed to keep growing as many shippers turn back to rail from road (EC, 2014, WorldBank, 2015, NBSC, 2015). Compared to road transport, rail option has disadvantages in flexibility but performs better in efficiency and environmental friendliness, especially in mid- or long-distance (more than 300 km) (Bergqvist, 2015). Many governments are now encouraging more freight on trains. For example, EC (2011) set goals to shift 30% of the road freight transport to rail and waterborne ways by 2030 and more than 50% by 2050.

Many countries' rail sectors have experienced deregulation and reorganization. With the influence of freer market and less impacts from government, newcomers can access to the business more easily and the overall price is more determined by the interaction of supply and demand. On the other hand, the inadequate cooperation of different parties in rail sector after deregulation may lead to some problems in allocation of profit and infrastructure investment. These issues may cause disruptions in the rail system, which are costly and menace the quality of rail freight transport.

Rail transport is pressed nowadays, as the volume of freight transport goods is increasing while its capacity and quality are not satisfying. Many old wagons¹ are still working in the system. Compared to more modern alternatives, their efficiency is lower and has more side impact on the rail track and external environment. In this case, shippers and undertakings need to know the condition of their wagons to further discuss whether to continue using the current ones or invest in new wagons. Authorities who manage the infrastructure and build regulations also need to understand different wagons to promote further policies and fees to incentive better-performance wagons. Therefore, relative methods are needed to evaluate the quality of rail transport and provide theoretical basis for various fees and regulations.

This thesis aims to identify different categories of costs in wagons' operation. Attention is focused on those costs that vary by the characteristics of wagon. Moreover, this thesis maps some basic relationships among variables in wagons and calculation of different operation and infrastructure related costs and effects. Then, it suggests a basic framework and a draft of an integrated tool to evaluate the performance of rail freight wagons.

In this section, the research's general information is introduced. The second section discusses the research methodology and methods adopted in this research. The third section collects information

¹ In this thesis, *wagon* means unpowered railway vehicles that are used for freight transportation. *Vehicle* particularly refers to rail vehicle which includes both wagon and locomotive. *Rolling stock* has similar meaning to *vehicle*.

from different aspects related to the index building and implementation. The fourth section lists method to calculate different types of costs by numbers reflecting the wagon's characteristics. In the fifth section the Rail Quality Based Index is introduced to evaluate wagon's performance and in the sixth section features of the index and implementation issues are discussed. The seventh section concludes the thesis's work and talks about further research possibilities.

1.2 Problem Statement

As mentioned above, the railway transport's volume has been increased steadily these years. Today, good owners have higher expectations on freight transport's quality. Infrastructure Managers (IMs) are also pressed to conduct with better operation method and minimum rail transport's externalities like disruptions and environment issues.

At the moment, RUs face trade-off of either bearing the low efficiencies of old wagons or big investment in purchase of new equipment in order to gain better performance. From the regulatory perspective, there is interest in stimulating the use of advanced rolling material, which minimizes wear and disruptions in the rail system. Various methods have been conducted to stimulate better wagons by the authorities such as fees, prohibitions and regulations.

Quality is the main consideration of wagons' performance. Different aspects of quality can be represented in cost and then be accumulated to reflect the wagon's condition in operation cost. In this way, an integrated tool to evaluate the performance of a wagon in cost is possible.

1.3 Research Purpose

The authors intend to build an integrated quality index that can be used to evaluate different freight wagons' performance. The index can represent the main quality aspects associated with freight wagons in the form of cost. By comparing the total operation cost with the benchmark in the industry, a rail quality index can be built to support different parties in rail freight industry.

In this thesis, the authors mainly focus to generate and review all possible components that can be included in the index. Costs that can be varied by the characteristics of wagons are focused. The authors also review the quantitative relation between a wagon's different characteristics and final costs but not to check the validity of formulas. Authors in the end come up with a draft of construction of the Rail Quality Based Index. However, the authors only suggest the possible parameters that can be included in the index construction in this thesis and the validation of them is left for further research.

1.4 Research Question

This thesis tries to answer the following questions and all the research questions shall be answered within the context of freight rail transport. The "wagon" implies freight wagons and all the costs are

calculated by year, as most of IMs and RUs charge/report cost every year.

RQ1: What kind of operation costs can be associated by the characteristics of wagons?

The “characteristics” are mainly the specifications of the wagon, which is decided by the type of the wagon. The specific condition of the wagon is partly concerned, that is, how the RU normally uses that type of wagon. The major concern here is the transport volume, which is determined by the operation speed, frequency, average load, etc. The detailed condition of the wagon is not concerned and average cost of the type of wagon is used.

RQ2: What aspects shall be considered when evaluating wagon’s performance?

This question can partly be answered by the first question, as all the aspects that lead to costs need to be collected. In addition, this research also generates some other aspects, mainly its externalities, which are not normally in form of costs today but may be charged on in the future.

RQ3: What methods can be applied to detect relation between wagon’s characteristics and final cost of each aspect? How to integrate them into an index to reflect the wagon’s quality?

This research does not directly investigate the relation between “characteristics” and the costs, which means first hand data is not collected. The research answers the 3rd question by collecting and gathering previous studies and opinions from experts.

The index is designed as a general construction without exact parameters. This is because the research does not collect first hand data to calculate those parameters and parameters in previous studies vary in different conditions. Another reason is also due to the data availability, as not all stakeholders in this industry would feel comfortable to public their cost situation.

1.5 Delimitation

This thesis focuses on rail freight transport so passenger wagons are not discussed. The context of this study is within Sweden and Europe; validity of the thesis beyond Europe is not tested. Attentions are mainly focused on the facilities’ and physical aspects of wagons’ quality, which are related to the characteristics of wagons. Quality aspects relating to service are not discussed, such as scheduling and in-station operation. Exact quality condition of one specific wagon is not studied; only operation behavior and standard specifications of wagons are taken as inputs of the initiated construction. Thus, the thesis just studies different performances among different types of wagons.

In the construction building, this thesis mainly focuses on its qualitative aspects, i.e., what components need to be considered and how they influence the final index. The calculations of the costs are not deducted by the authors with first hand data. Researches on the relations between selected components and costs are reviewed and used in the final construction of index. The thesis defines and names parameters of the construction from formal studies but not quantify them.

2 METHODOLOGY

Methodology refers to the approach to process of the research, comprising a set of methods (Collis and Hussey, 2013). In the business research process, appropriate methodology can be an efficient guidance for researchers to accomplish the research goal. In this section, four aspects have been discussed, i.e. research strategy, research design, data and research quality.

2.1 Research Strategy

Research strategy explains rationale of the research and the principles to guide the thesis. Therefore, both research paradigm and research approach should be clarified before conducting the research. This can prevent the research procedure from going astray. In the following section, research paradigm and research approach have been discussed respectively.

2.1.1 Research Paradigm

According to Collis and Hussey (2013), a research paradigm is the philosophical framework which guides how research should be conducted. There are two main research paradigms have been identified, which are positivism and interpretivism.

Positivism is an epistemological position that advocates the application of the methods of the natural sciences to the study of social reality and beyond (Bryman and Bell, 2011). From this point of view, it agrees on these principles that the social world exists externally and is viewed objectively; the research process is value-free; the researcher takes the independent role of an objective analyst (Blumberg et al., 2011).

The alternative to positivism is interpretivism. Unlike positivism, the basic assumption of interpretivism is that the social world is not objective but highly subjective. Under the guidance of interpretivism, researchers consider they are part of what is observed and the research procedure is driven by subject interests (Blumberg et al., 2011).

Despite the distinctions between the two paradigms, they can exist in same research procedure. This means the research paradigm can be a combination of the two main paradigms. In this study, the research procedure has been conducted generally under the guidance of positivism. This is because the nature of this research is to map out the object cost, which relates little with researchers' subject opinions. The methods to calculate the costs are collected from previous positivistic researches and experiments. However, this research has some portion of interpretivism paradigm because the constructions of the final index and implementation suggestions are explained with author's subjective idea and previous interpretivistic methods.

2.1.2 Research Approach

Research approaches are plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis and interpretation (Creswell, 2013). Totally, there are three main research approaches, quantitative approach, qualitative approach and mixed approach.

Quantitative research can be constructed as a research strategy that usually emphasizes quantification in the collection and analysis of data (Bryman and Bell, 2011). On the other hand, qualitative research is defined as a research strategy that usually emphasizes words rather than quantification in the collection and analysis of data (Bryman and Bell, 2011). Generally, quantitative approach is a deductive process, which is associated with positivism and qualitative approach is an inductive process, which is associated with interpretivism.

The distinction between quantitative and qualitative research is framed in terms of using numbers rather than words, or using closed-ended questions rather than open-ended questions (Creswell, 2013). Therefore, neither quantitative nor qualitative approach can give researchers a comprehensive understanding of the research separately. Besides these two approaches, mixed approach is a combination of both quantitative and qualitative ones. Mixed methods approach is an approach to inquiry involving collecting both quantitative and qualitative data, integrating the two forms of data, and using distinct designs that may involve philosophical assumptions and theoretical frameworks (Creswell, 2013).

In this sense, research approach employed in this study is more in a quantitative way as the research is generally under the guidance of positivism. Most data collected is in quantitative form, such as formula and number, in order to find out the connection between wagon's characteristics and costs.

2.2 Research Design

Defined by Bryman and Bell (2011), a research design provides a framework of data collection and analysis. Designing a research includes a large variety of methods, techniques, procedures, protocols and sampling plans. Researchers are able to achieve greater insight into the research by conducting an appropriate research design (Blumberg et al., 2011).

The entire research procedure in this study has five steps. The first step is reviewing previous studies in terms of wagon's quality and relevant aspects. The second step is conducting interviews to get further accesses to available data and materials. Both the first step and second step can be implemented simultaneously. In the third step, the combination of the first two steps builds the theoretical framework associated with wagon's cost and index building. Next, the fourth step is proposing the index construction based on the theoretical framework. In the last step, the authors discuss some implementation issues of the index.

All these steps are shown in Figure 1.



Figure 1. Research Design Steps

2.3 Data

Data are the facts (attitudes, behavior, motivations, etc.) collected from respondents or observations (mechanical or direct) plus published information (Blumberg et al., 2008).

Data can be divided from the sources they come from. Primary data are those generated from an original source such as people's own experience and surveys. Secondary data are collected from existing sources such as publications, databases and internal records. Data can also be divided by their natures, including qualitative data and quantitative data for statistical analysis. (Collis & Hussey, 2013)

Qualitative data are in nominal (named) form. They are normally transient, understood only within context and are associated with an interpretivist methodology that usually results in findings with a high degree of validity. Data for statistical analysis is collected when designing a positivist study. The quantitative data are in numerical form. They are normally precise, captured at various points in time and in different contexts, and are associated with a positivist methodology that usually results in findings with a high degree of reliability (Collis & Hussey, 2013).

Most data used in this research are quantitative data to find the objective connection between wagon's features and final costs. Some of the data, for example the wagon's brake system, are still in qualitative form. This is because limit previous studies tried to quantify these forms of data and their connection to final costs are not fully investigated.

2.3.1 Data Availability

Each year, IMs in EU countries would publish Network statements for their respective countries. Content of Network statement is regulated and one chapter of the statements is about charges. Differentiated charges of EU countries and variables decide the charges can be collected from those publications.

Due to the inputs and variables that reflect characteristics of wagons, the International Union of Railways (UIC) has classification system of all different types of wagons and locomotives. This can simplify the naming systems from different authorities. At the same time, the Interfleet Group in Sweden has a FORD system, which includes detailed information of vehicles operating in Sweden. But the system is only available to its users and close to public.

Information about how the parameters of the relations between charge tariffs and input variables are calculated is also available. There are researches to detect the exact parameters in different countries and conditions. First hand data are collected by designed facilities in these researches. In this case, the exact parameters may vary by specific conditions but the type of mathematical relation is collected as qualitative data in this research.

Previous studies also focused on index building issues. Literatures discussing method to build an index, to set the benchmark and use the index can be found. Indexes in transport industry are also available as reference of this research.

2.3.2 Data Collection

Both quantitative and qualitative data are collected in this research. Quantitative data are from publications, databases and data gathered from previous studies. Outcomes and conclusions of some previous studies are also considered as quantitative data. The research also includes qualitative data collection, which includes results from the analysis of previous studies and index building methods. The qualitative data is also collected through interviews.

Knowing there are many sub-topics this research need to cover and the sensitivity of data publicity to different stakeholders, this research collected data from more theoretical way. This means the authors collect more data on how to calculate the cost than how the authorities/companies charge costs. Further, as the thesis continues, experts/stakeholders in one sub-industry are found to have limited knowledge to other sub-industries. For example, experts in maintenance industry have less information on how RIs us their wagons. Experts interviewed would prefer to provide rough numbers to help the authors better understand the industry, however those data are not applicable to academic researches. This means many of the results from interviews themselves are not directly displayed in this research. However, this research is more benefited from publications, articles and other materials provided by the interviewees.

Interviews

Interview is a method for collecting data in which selected participants (the interviewees) are asked questions to find out what they do, think or feel (Collis & Hussey, 2013). Interviews can be conducted as personal interview (face-to-face communication), telephone, mail, computer or a combination of these (Blumberg et al., 2008).

Semi-structured interview is a form of interview in which the researcher prepares some questions to encourage the interviewee to talk about the main topics of interest and develops other questions during the course of the interview. The order of the questions is flexible and not all of the prepared questions need to be asked as the interviewee may provide relevant information under other questions (Collis & Hussey, 2013).

The interviewees in this research are experts in rail freight transport related industries. Interviews with experts in the industry help the authors to better understand the research industry and select the

components of the Rail Quality Based Index. The number of interviewees is not set in the beginning of the research and data accesses is requested from the interviewees if possible. The potential interviewees are selected in governmental authorities/IMs (e.g., Transportstyrelsen and Trafikverket), RUs (e.g., Green Cargo, HectorRail, and SCT transport), maintenance companies (e.g., SweMaint, EuroMaint), wagon manufacturers and wagon keepers (Bombardier, Transwagon) and also research institutes and individuals (e.g., VTI, KTH, CTH and GU).

The actual interview guide is shown in Table 1. Further information can be found in the appendixes.

Table 1. Interview guide

Interviewees	Organization	Purpose	Method
Anders Ekberg	Chalmers University of Technology	Data and methods to calculate infrastructure cost	Email
Anna Pernestål Brenden	Interfleet Group	Data availability in FORD system as input of this research	Email/Phone
Bo-Lennart Nelldal	Royal Institute of Technology	Data and methods to calculate maintenance fees	Email
Charlotte Högnelid	Trafikverket	Methods to decide infrastructure charges	Email
Jonas Floden	University of Gothenburg	Data and methods to calculate maintenance fees	Email
Pär-Erik Westin	Trafikverket	Methods to decide infrastructure charges	Email
Robert Bylander	Transportstyrelsen	Methods to evaluate and approve wagons	Email/Phone
Tomas Forsberg	SweMaint AB	Data and methods to calculate maintenance fees	Email/On site

In this research, different communication methods are combined and the exact method varies by interviewees. Before the interviews, regardless the exact methods, an email is sent to the potential interviewees to introduce the research and brief the possible questions. This can give the respondents time to prepare and present precise answers.

Personal interview is preferred. The advantage of this face-to-face method is that it can help to get complex and sensitive answers and secure the depth of information and detail (Blumberg et al., 2008, Collis & Hussey, 2013). Due to the limits of cost and time, personal interview cannot be conducted with all respondents. Telephone and online telephone interview is used to overcome the geographical constraints.

2.4 Research Quality

2.4.1 Reliability

In Collis and Hussey (2013), reliability refers to the accuracy and precision of the measurement and

the absence of the differences if the research were repeated. If a research is with high reliability, a repeat study shall have the same result and replication is important especially in positivist studies.

Reliability tends to be high in positivist studies but in interpretivist paradigm the reliability may have less importance. This is because, in the interpretivist paradigm, the researchers are believed to influence the result of the study thus replication is difficult to reach (Collis and Hussey, 2013).

Reliability of this research is reached by various reliable data used. Publication and regulation are collected from reliable authorities and organizations. Data from different contexts are generalized and explained. Previous researches are reviewed and common opinions are extracted from different authors. Special features of different cases and countries background are tried to eliminate and keep their common places. Interviews are conducted with people related to the topic field and similar questions are put to different respondents to keep the answer objective. The method of data collection is kept neutral and proper to ensure its reliability.

2.4.2 Validity

According to Collis and Hussey (2013), validity is the extent to which a test measures what the researcher wants it to measure and the result reflects the phenomena under study. Errors in procedures, poor samples and inaccurate or misleading measurement can lower the validity.

Validity can be accessed in different ways. The most common way is face validity. The face validity ensures that the tests or measures used by the researcher do actually measure or represent what they are supposed to measure or represent. Construct validity relates to the problem that there are a number of phenomena that are not directly observed, which are called hypothetical constructs, such as motivation and the satisfaction (Collis and Hussey, 2013).

A snowball strategy is conducted in the data collection period. Data in this research are collected with previous studies and experts in the topic industry. Studies and further potential respondents are also inquired in interviews. And the data are analyzed and displayed with a same object and unit type to avoid bias and misleading.

To further enhance the validity, the index construction's parameters shall be detected and continuously revised by experts in research industry and future potential users.

3 THEORETICAL FRAMEWORK

In this section, related knowledge to railway transport's cost and index building is reviewed. The first part of this section introduces a simple background and further introduction of Rail transport. UIC classification and FORD system are also reviewed in the first part, which record wagon's characteristic information and can potentially be used as inputs of the Rail Quality Based Index. The second part reviews different types of quality issues. The third part of this section concludes current situation of infrastructure charges in Europe with the help of UIC publication. The fourth and fifth part reviewed methods to set benchmark and indexes. Some indexes using in transport industry are also reviewed as references. In the sixth part the Bonus-malus system is reviewed as a potential method to use the index in future implementation.

3.1 Background of Rail Transport

Railway is a permanent track composed of a line of parallel metal rails fixed to sleepers, for transport of passengers and goods in trains. And rail transport is (CollinsDictionary, 2015),

“The system of taking passengers or goods from one place to another by railway”.

The earliest evidence of railway was the Diolkos wagonway in Greece during the 6th century BC, which are actually grooves in limestone. By that time the truck running on the railway was still powered by man and after that animals were used as power. In 1804, after James Watt patented his steam engines in 1769, Richard Trevithick demonstrated the first locomotive-hauled train equipped with high-pressure steam technique, which is more suitable for the movement of a train (NationalMuseumWales, 2008). In 1825, the establishment of the first public steam railway in Britain marked the start of modern railway transport.

As a key element of industrial revolution, railway transport reduced the costs of transport, and allowed for fewer lost goods when comparing to other transport methods. Many countries started to invest into railway and locomotive technology in the mid-nineteenth century for rail transport's speed, convenience and low cost. Considering the strict requirement in fuel and water supply and higher manual cost after World War II, steam locomotive was increasingly costly and the railway was also threatened by other means of transport. Road transport developed rapidly after the war whilst the high operation and transshipment cost made rail transport less competitive.

Due to the high cost of steam locomotives, diesel engine were introduced to carry a train and now many of them are electrified. Many innovations have taken place in both the trains and the infrastructures such as the material of the track and the train. Beyond that, trains, stations and terminals also saw improvements in operations, which lowered the relative cost and accelerated the overall speed.

Nowadays, there is a total more than 1.3 million km's railway length in the world, in which the

United States has about 220,000 km, followed by Russia, China, India and Canada, for 60,000 to 90,000 km each (IndexMundi, 2012). EU-28 in total has 215,000 km in 2012, of which Germany and France each has a share of more than 30,000 km (EC, 2014).

The total rail freight transport in EU-28 countries was 407 billion tonne-km in 2012, and the number of rail passenger transport was 418 billion passenger-km. The share of rail transport remained about the same since 1995, about 11% and 6.5% respectively of total freight and passenger transport. The United States had 50% more freight transport in total volume than EU-28 but the share was 43% in the year of 2011. The passenger rail share was almost negligible in the States (0.5% in share since 1990), and 80% of the citizens traveled by car (EC, 2014). In China, railway always plays important role in passenger transport and contributed about 40% share in total since 1990. The freight rail transport has tripled since 1990 but the total freight transport was 4 times larger in the year of 2014 (NBSC, 2015).

Rolling stocks are vehicles that move on rails, including locomotives and wagons. According to the Collins Dictionary (2015), rolling stock is referred as,

“The wheeled vehicles collectively used on a railway, including the locomotives, passenger coaches, freight wagons, guard's vans, etc.”

Specifications of rolling stocks are different in different areas but the main types are similar. Locomotives in use nowadays are mostly electrified, while some of them are still powered by diesel. The steam-powered locomotives have mostly been replaced now for its inefficiency. Other than passenger wagons, covered wagon (U.S., boxcar), open wagon (U.S., gondola car) and flat wagon are main types of wagon in freight transport. Types such as refrigerated wagon, tank wagon, etc. are also applied for different uses (Bergqvist and Zuesongdham, 2010). Boxcar and gondola car are shown in Figure 2 and Figure 3.



Figure 2. Boxcar 70 ton 50 feet

Source: MildwestRailcar (2015)



Figure 3. Gondola Car

Source: TedHikel (2014)

Bogie is a chassis or framework carrying wheels, attached to a vehicle, thus serving as a modular subassembly of wheels and axles. Bogies help the train body to run stably on both straight and curve track. They also responsible to absorb vibration generated by track irregularities and lower the train's influence on the track (Okamoto, 1998). The bogie structure is shown in Figure 4.

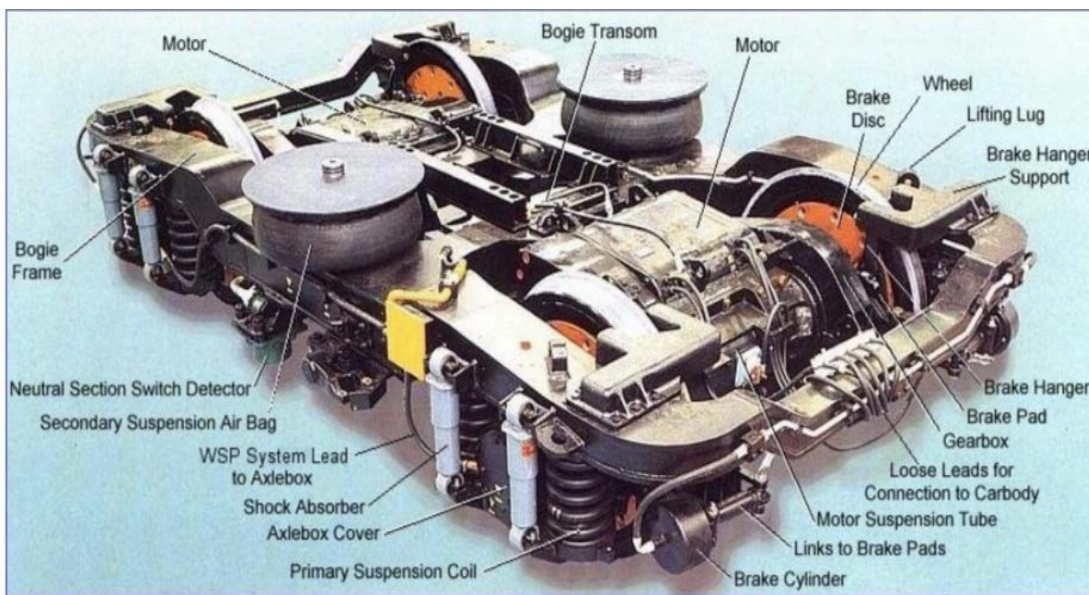


Figure 4. Bogie Structure

Source: RailwayTechnicalWebPages (2015)

3.1.1 UIC Classification

International Union of Railways (UIC) is the worldwide international organization of the railway sector, including 202 members across all 5 continents. The mission of UIC is to promote rail transport at world level and meet the challenges of mobility and sustainable development.

UIC classification is a comprehensive system for describing the characteristics of rolling stocks. There are both classifications of locomotives and wagons. Each classification is introduced respectively in the following part.

UIC classification of locomotives axle arrangements

The UIC classification of locomotive axle arrangements describes the wheel arrangement of locomotives, multiple units and trams. Different orders and combinations of letter, number and signs represent different arrangements of locomotives' axles. The explanation of letters, numbers and signs is shown in Table 2.

Table 2. UIC classification of locomotives axle arrangements.

Elements	Meaning
Upper-case letters	The number of consecutive driving axles, starting at A for a single axle. C thus indicates three consecutive pairs of driving wheels;
Numbers	Consecutive non-driving axles, starting with 1 for a single axle;
Lower-case "o"	Suffixing the driving wheel letter: axles are individually driven by separate traction motors;
Prime sign "' "	The axles are mounted on a bogie;
Plus sign "+"	The locomotive or multiple unit consists of permanently coupled but mechanically separate vehicles;
Brackets"()"	Group of letters and numbers describing the same bogie;
Suffixes	Characteristics of locomotives represented in letter or number;

Source: Wikipedia (2015)

For example, the most common wheel arrangements in modern locomotives are Bo'Bo' and Co'Co'. Bo'Bo' means two bogies under the unit, each bogie has two powered axles individually driven by traction motors, whilst in Co'Co' there are three powered axels in each bogie.

UIC classification of goods wagons

UIC's classification of goods wagons is made up of a category letter in capital and several index letters in lower cases.

Categories are shown in Table 3. Each category of goods wagon is given a type number, who forms the fifth digit of the 12-digit UIC wagon number.

Table 3. UIC classification of goods wagons

Class	Wagon type	1st digit of type number
E	Ordinary open high-sided wagon	5

F	Special open high-sided wagon	6
G	Ordinary covered wagon	1
H	Special covered wagon	2
I	Refrigerated van	8
K	Ordinary flat wagon with separate axles	3
L	Special flat wagon with separate axles	4
O	Open multi-purpose wagon (composite open high-sided flat wagon)	3
R	Ordinary flat wagon with bogies	3
S	Special flat wagon with bogies	4
T	Goods wagon with opening roof	0 (before 1988: 5)
U	Special wagons	9
Z	Tank wagon	7

Source: Wikipedia (2015)

After the category letter, there are a series of lower case letters that represent characteristics of goods wagons. Each lower case letter (or combination like “aa”, “bb”) has different meaning when following different capital letter, i.e., different categories. For example, in “Hbbllns” wagon, “H” means it is a special covered wagon. In the following letters, “bb” means the wagon has separate axles and loading length of 14 m or more, “i” means opening side walls, “ll” represents the wagon has lockable partitions, “n” shows the maximum load of 25t and “s” is the permission of speed up to 100km/h.

UIC wagon numbering

Rolling stock numbers enable a wagon to be identified and form a common language among RUs, infrastructure companies and the state authorities.

The complete wagon number comprises 12 digits. The first two digits describe the wagon’s interoperability code or a tractive wagon (locomotive)’s type of traction. The 3 and 4 digits show the wagon’s belonging country. 5 to 8 digits are the wagon’s type information, in which the 5th digit shows the wagon’s class as mentioned above. 9 to 11 digits are individual running number and the last digit is a self-check digit.

3.1.2 FORD System

FORD system (Fordonsdatasystemet) is a vehicle information system developed by Interfleet to Sweden’s railway sector. FORD is a collective system of a number of rail vehicles’ technical information, aiming to monitor and control vehicles’ maintenance conditions (mynewsdesk, 2007). Almost every rolling stocks operating in Sweden are registered in the system. Each vehicle, including freight wagon, passenger wagon and locomotive are given a unique registration number in the system. The number itself, unlike the UIC number, does not explain anything itself. Relevant information can be loaded accordingly to the registration number (Brenden, 2015).

FORD system contains vehicles' information in detail. It includes vehicle's specifications of each component. Due to freight wagons, the system records wagon's brake type and also bogie information. The system also has information about wagon's using and maintenance condition. Wagon's usage is recorded by distance, however more detailed information such as speed and brake usage are not guaranteed. Users of the system are maintenance factories, RUs, vehicle owners, and Entities in Charge of Maintenance (ECM) (Brenden, 2015).

3.2 Rail Quality

Rail quality involves all quality components in the rail transport system, which includes different categories (e.g., service and infrastructure) that can hardly be easily evaluated identically. This shows that rail quality is a broad concept with abundant connotations. In this thesis, rail quality evaluation mainly concerns quality issues can be differentiated by characteristics of rolling stocks, i.e. rolling stock quality, track quality and relevant external quality.

3.2.1 Rolling Stocks Quality

Typical railway system is the train-track system, which mainly consists of two parts, rolling stocks and infrastructure (track).

When considering the rolling stock itself, researches on rolling stock failure and maintenance have been reviewed respectively. Generally, failure in rolling stock wheels is mainly attributed to three reasons, i.e. surface wear, wheels flat and rolling contact fatigue (Palo, 2012). Wear is the loss or displacement of material from a contacting surface (Moyar and Stone, 1991). Different types of steels employed in wheels have different wear rate and several mechanism parameters would also affect the wear condition, e.g. axle load and vehicle speed. Wheels' flat is another kind of failure and is caused by the hard friction between wheels and rails. Rolling contact fatigue (RCF) is one of the main modes of wheels failure. Comparing to surface wear, RCF is more harmful to vehicle wheels as it can cause damage to both wheel and rail (Magel, 2011).

Earlier studies with regard to rolling stock failure conducted in two aspects, i.e. wheel materials and wheel-rail contact. One study analyzed material selection in rolling stock wheels (Mädler and Bannasch, 2007). In this research, new wheel materials have been tested in laboratory and in service situations, then conclusion has been drawn that the wheel material employed and the manufacturing quality of wheel influence the wheels wear and limit the wheels' life. Braghin et al. (2006) developed a wheel profile wear prediction model to simulate the wheel wear process with full-scale tests carried out on laboratory conditions. This model is based on three parts, i.e. a vehicle's multibody model, a local contact analysis model and a local wear model. It can be used to determine the best re-profiling interval that can minimize total life cycle costs. This model has been tested in real standard service and results shown that a re-profiling of the wheel after about 200,000km would be the appropriate re-profiling point. This model can also be used to determine the vehicle design parameters that determine less wear in wheel and rail. Telliskivi and Olofsson (2004) simulated the form change of wheel-rail contact. The simulation can help to identify risks caused by increased train speeds and axle loads, thus can be a basis for a more efficient maintenance schedules for track and rolling stock.

Aforementioned review shows that rolling stocks have various types with different functions. Different types of wagons have some common quality issues, e.g., the wheels quality. Among all quality indicators in the rolling stock, the quality of wagon wheels determines the stability of a vehicle (Barke and Chiu, 2005). Wheels condition can affect the performance of rolling stock in two different ways, i.e. safety and dynamic performance (Bladon et al., 2004). Therefore, the evaluation of wheels quality is necessary.

The rolling wheel quality is determined by several factors, in which two main reasons are rolling wheel materials and wheel-rail contact. Initially, material used in the rolling stock wheels has significant influence on rolling wheel quality. The major material of wheels is steel. These steels predominantly have pearlitic structures containing hard cementite lamellae which can guarantee high resistance to wear (Mädler and Bannasch, 2007). Another reason that affects rolling wheel quality is the wheel-rail contact. The interaction between wheels and rails would lead to material deterioration.

Like other transport system, rail transport system would degrade over time and the quality of each component, e.g. safety and reliability, would decrease concomitantly. The breakdown of rolling stock would cause the disruption in rail transport system. This therefore calls for maintenance operations to guarantee the rail transport performance level.

According to Esposito and Nocchia (2008), rail maintenance is defined as a collection of activities to conduct railway operations with regard to quality parameters, i.e. efficiency, safety and comfort. This shows that maintenance can be seen as a quality-based issue acts as an indicator to reflect the quality performance. The object of maintenance is to reduce the failure rate while minimizing the overall cost of rail operations. Maintenance brings the system back to acceptable condition and keeps the quality performance above requirements.

Maintenance types can be basically divided into two categories, i.e. corrective maintenance and preventive maintenance. Corrective maintenance is to fix the random failure occurs in the structure and preventive maintenance is scheduled with predetermined time interval. Regardless of the maintenance type, features of rolling stocks, especially the wheels' condition, are the foundation of whole maintenance procedure. In Figure 5, rolling stocks maintenance procedure is illustrated.

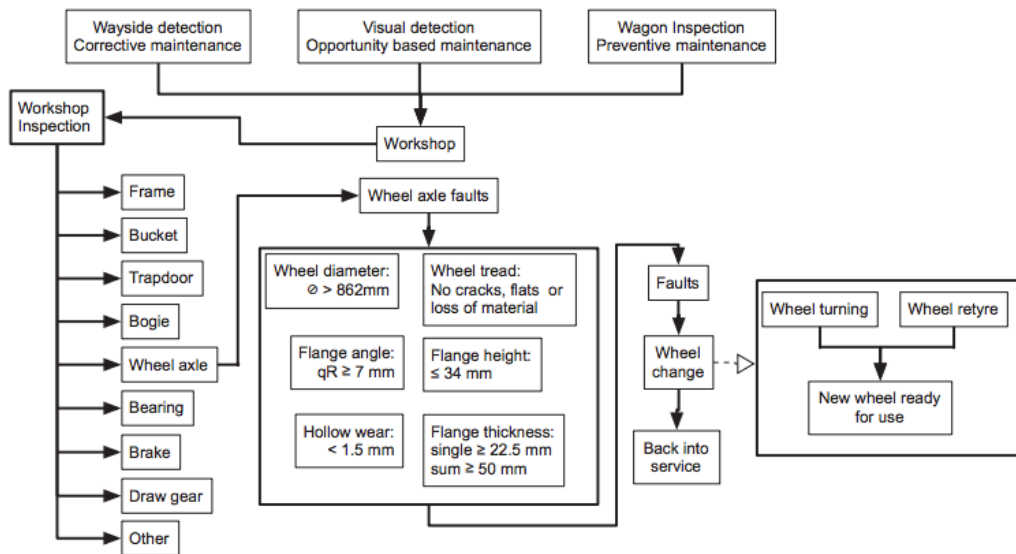


Figure 5. Rolling Stocks Maintenance Procedure

Source: Palo (2014)

3.2.2 Track Quality

The track on a railway or railroad, also known as the permanent way, is the foundation infrastructure of rail transport system. It consists of two parallel rows of long pieces of steel and supports passengers and cargo from origin to destination. In details, track is the structure consisting of the rails, fasteners, sleepers, and ballast, plus the underlying subgrade. In the electrified and 3rd rail tracks system, there are two more components, electricity lines and connectors. Each component has a specific function and has effect on others. Laying the rail has many concerns such as the choice of route and angle, and all of them influence the interaction between wheels and track. The gauge of the rail is different. The standard gauge is 1435mm, which is adopted in most of the Europe countries, China and the United States. There are also 1067mm gauge in Japan and Taiwan and also 1520mm in CIS countries. Track structure is shown in Figure 6.

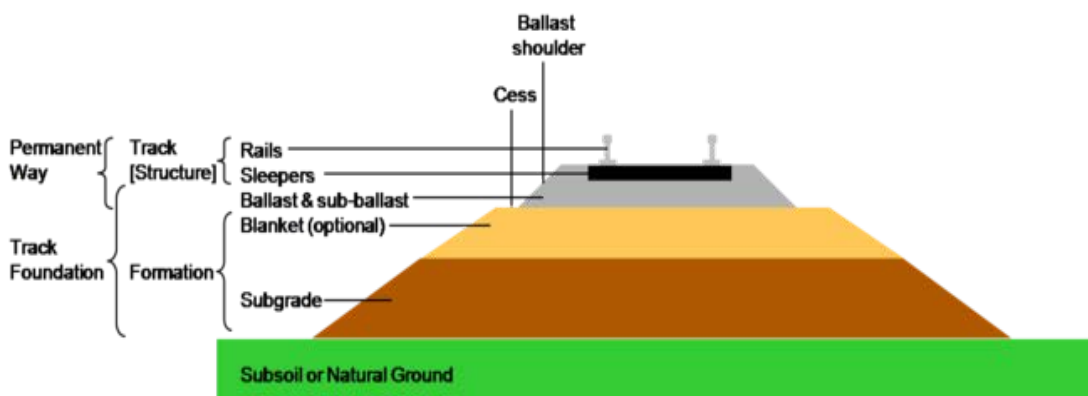


Figure 6. Structure of rail track

Source: Wikipedia (2015)

Rail track quality is related to rolling stocks due to the interface between wheel and rail. Therefore, similar to rolling stock maintenance, the rail track maintenance should also consider several common issues, especially safety and cost. Besides, some studies used the national data and investigated the track maintenance cost. Johansson and Nilsson (2004) analyzed the track maintenance costs for different track units using Swedish and Finnish railway data. Andersson (2011) analyzed maintenance cost for Swedish railway infrastructure in relation to traffic volumes and network characteristics. Log-linear and Box-Cox regression models were applied (Log-linear for the dedicated freight lines and Box-Cox for the lines mixed passenger and freight traffic). The result shown that the cost elasticity is found to be higher for passenger trains than for freight trains in the case of mixed lines. The cost elasticity for freight trains on dedicated freight lines is found to be higher than for freight trains on mixed lines.

Rail infrastructure in broad way also includes facilities related to rail transport. It also includes stations, handling equipment, bridges, tunnels, etc. and relative operations of them. However, these would not be discussed in this study.

3.2.3 Externality

Rail transport system is not a closed system so there are externalities. Therefore, when considering the rail quality, other relevant quality issues should also be included, e.g. environment performance and accidents.

Externality can be defined as (CollinsDictionary, 2015)

“An economic effect that results from an economic choice but is not reflected in market prices.”

External cost is the cost imposed on a third party when producing or consuming a good or service (EconomicsHelp, 2015). When externality exists, the external cost appears. From the transport perspective, when the taxes and charges are equal to the costs which are imposed to society by transport users, they will take the external costs into account in their decision making, resulting in some changes, e.g. changing vehicle type and transport volume (Delft and Infrac, 2011).

The topic of transport externalities has been further developed these years by different European research projects. According to Delft and Infrac (2011), external costs have been calculated into five categories, i.e. accidents, air pollution, climate change, noise and congestion. The same external costs among different transport modes (e.g. road and rail, passenger and freight) are different. According to Matsika et al. (2013), in rail transport system, the externalities can be divided into three categories, mainly according to the practical feasibility of their translation into external costs . The categories are,

- It is possible to directly translate into external costs for producers and/or users;
- It is possible to directly translate into external costs for the Community;
- It is not possible to directly translate into external costs;

Among all these external cost categories, noise generated by freight trains is one typical externality

in the rail transport system. Noise is the unwanted sounds that cause negative effects to humans. Thompson and Jones (2000) discussed the reasons that cause rail noise and reviewed the modeling of wheel/rail noise generation. In this research, wheel/rail noise generation have been divided into three types, which are generated by,

- Unevenness of the wheel/rail running surfaces;
- Wheels running over discontinuities at rail joints, dipped welds or points and crossings;
- Sharp curves (squealing noise);

In general, there are two main negative effects caused by rail noise, i.e. annoyance and health damages (Delft and Infrac, 2011).

In the EU region, all freight wagons should be checked that the wagons fulfill requirements regarding environment according to TSI. TSI, namely Technical Specification for Interoperability, is the specifications for EU rail transport system to meet. The aim of TSI is to ensure the interoperability of the European Community's high speed and conventional rail systems (ERA, 2014).

TSI noise regulation is the specification relating to the rolling stock noise authorized by EC and the requirements in TSI noise regulation are all the same in EU countries. The TSI noise regulation has been implemented since June 23rd 2006. This regulation only aims for new freight wagons. For old wagons, which have been put into operation before the implementation date, the TSI noise does not apply. However, if the old wagons are retrofitted or modernized, the homologation is necessary and all retrofitted wagons are required to pass the standardized noise test (KCW, 2009).

The noise generated in different categories of rolling stock subsystems is allocated to four basic categories. In each noise category, the ceilings are set specifically. The TSI noise emissions ceilings for freight wagons are illustrated in the Table 4.

Table 4. TSI Noise Emission Ceilings for Freight Wagons

Type	Limit Value
New wagons with an average number of APL (*) up to 0,15 m [^] (-1) at 80 km/h	82 dB(A)
Renewed or upgraded wagons according to Article 14(3) of Directive 2001/16/EC with an average number of APL up to 0,15 m [^] (-1) at 80 km/h	84 dB(A)
New wagons with an average number of APL higher than 0,15 m [^] (-1) to 0,275 m [^] (-1) at 80 km/h	83 dB(A)
Renewed or upgraded wagons according to Article 14(3) of Directive 2001/16/EC with an average number of APL higher than 0,15 m [^] (-1) to 0,275 m [^] (-1) at 80 km/h	85 dB(A)
New wagons with an average number of APL higher than 0,275 m [^] (-1) at 80 km/h	85 dB(A)
Renewed or upgraded wagons according to Article 14(3) of Directive 2001/16/EC with an average number of APL higher than 0,275 m [^] (-1) at 80 km/h	87 dB(A)

Source: KCW (2009)

3.3 Infrastructure Charges in Europe

Since the formation of the European Economic Community in the 1950s, forming a common European transport policy has always been a goal. With the establishment of EU, numbers of reforms have been adopted and one of them is the deregulation in the rail sectors, which separate the infrastructure management and train operations. Each country's infrastructure manager has infrastructure's charging scheme that governs how RUs are charged for capacity use. The tariff of each country is published annually in a Network Statement as required by a European Directive.

In 2012, UIC reviewed the railway infrastructure charges in Europe (Teixeira and Pita, 2012). In the review, UIC classified tariff systems into categories depending on how they are structured and presented to the railway users. Four categories of calculation structure have been identified: simple, simple-plus, multiplicative and additive.

3.3.1 Charging Types

A simple system charges a base price per train-km or per tonne-km, without any additional parameters. A simple-plus system may also include additional parameters and classifications of train characteristics. Multiplicative system has a base price and various multiplicative factors to calculate a final price. An additive system is a sum of multiple parts and each part may be simple, multiplicative or calculated by some other type of formula.

3.3.2 Charging Philosophy

From an economic point of view, most tariff systems can be divided into marginal cost and full cost systems. Marginal cost system charge the marginal cost of adding a train in the system, whilst the full cost system charge the railway user the full cost, which including initial investment cost, divided by the demand. The tariff system philosophy and type is not always clear.

Variations also exist base on the aforementioned two types. For example, a marginal cost plus system adds additional charges to recover a part of the full costs. A full cost minus system gives the railway users discounts on the full costs.

3.3.3 Charging Concepts

UIC identified a number of general variable categories from all reviewed countries. The variable categories are,

- Access
- Capacity Reservation
- Train Movement
- Energy/Electricity
- Maintenance

- Safety/Security
- Congestion
- Environmental/Noise.

In the 27 countries, 26 of them have train movement tariff. 17 countries impose charges for using the electrical system or for consuming electricity. 14 countries charge for reserving capacity and 10 have access charges. There are also countries have fees for congestion, safety/security, environmental and infrastructure maintenance.

3.3.4 Charging Variables & Variable Categories

UIC split existing tariffs' variables into five categories. Within each of these categories is a subcategory of variable types and within each subcategory are the variables that are used for each of the tariff system. The five main categories are,

- Rolling Stock and Traction Type
- Offered Services
- General Service Type
- Type of Path
- Type of Infrastructure Used

Each category is introduced respectively in the following parts.

Rolling Stock and Traction Type

Within the rolling stock and traction type category there are subcategories of electricity consumption, traction type and train characteristics and wear and tear.

The electricity consumption subcategory is charged in,

- Days
- Electrical train-km
- KW-hour consumed
- Liters of diesel consumed.

The traction types includes,

- Diesel
- Electric
- 3rd rail
- Other.

There is also subcategory looking at train characteristics and wear and tear considers. Variables under this subcategory includes,

- Train mass or mass per train axle
- Number of axles
- Number of Pantographs
- Number of trucks
- Whether or not the train has a tilting mechanism
- Train Speed
- Train Type (passenger, freight, etc.)

Offered services

The offered services category considers differentiation of different by service type. It can be further subcategorized into performance indicators, stations and unit charges.

The performance indicators subcategory considers punctuality, rail capacity and congestion issue. Station subcategory charges for relevant services in stations. This subcategory considers the systems in stations, influence of number of passengers and stop time at stations. Unit charges include number of trains, train-km ordered and also charges base on seat-km, tonne-km and train-km.

General Service Type

The general service type can be categorized into the following subcategories. The type of agent can differentiate charges, as sometimes payment needs to be segregated by different companies. The domain subcategory considers the geographic characteristics on whether the service is local, regional, domestic or international. Charges can also be varied by set tariff zone where the line or station prices differ from zone to zone. The traffic type, i.e., passenger or freight, is also one consideration of domain subcategory. The frequency subcategory looks at the total number of ordered km or train paths per timetable period.

Type of path

The type of path category considers the type of path that is being requested.

The subcategory of path includes the number of path-km ordered and the type of path requested (normal, direct or slow). Time is also a subcategory differentiates charges. It can be charged for the entire timetable period, differing charge for business or holiday, per day for the number of days using a service, etc. A flat fee can also exist for the entire year. The traffic subcategory looks into charges at various traffic levels and types of contracts. The transport subcategory differs in priorities for different levels and some special transport conditions.

Type of infrastructure used

The type of infrastructure has three subcategories. The first one concerns characteristics of network. Category and type of line, rail gauge, mass limit and section speed limit are considered in the network part. Specific subcategory charges for special infrastructure, i.e., bridge, tunnels, etc., and other definitions of infrastructures. Charges may also exist for different scale of station.

3.4 Benchmark

Benchmarks are the standards that are used in the method of benchmarking. According to the latest version of Collins Dictionary (2015), benchmark is

“A standard or point of reference in measuring or judging quality, value, etc.”

3.4.1 Benchmarking

Benchmarking has been existed for many years as a method to improve the focal object's performance. It helps to sustain long-term success through continual comparison and learning from other organizations.

The Global Benchmarking Network (Mann et al., 2010) considered benchmarking as a management technique with many definitions. They classified benchmarking into two main categories, informal and formal benchmarking.

Informal benchmarking can be defined as an unstructured approach to learn from the experience of other organizations. In other words, no defined processes are necessary. This kind of benchmarking is almost used by everyone unconsciously at work and in daily life. It is people's nature to compare and learn from others' behavior and practices – such as talking with colleagues and learning from their experience, consulting with experts and utilizing online databases.

Formal benchmarking is conducted consciously and systematically. Two more categories can be further divided: performance benchmarking and best practice benchmarking. Performance benchmarking describes the comparison of performance data obtained by studying similar processes or activities. It may include the comparison of financial measures like different costs and non-financial measures such as time and percentage. Best practice benchmarking describes the comparison of performance data obtained by studying similar processes or activities and identifying, adapting, as well as implementing the practices that revealed the best performance results. It focuses on “actions” – i.e. doing something with the comparison data and working out why other organizations are achieving higher levels of performance. Benchmarking types are shown in Figure 7.

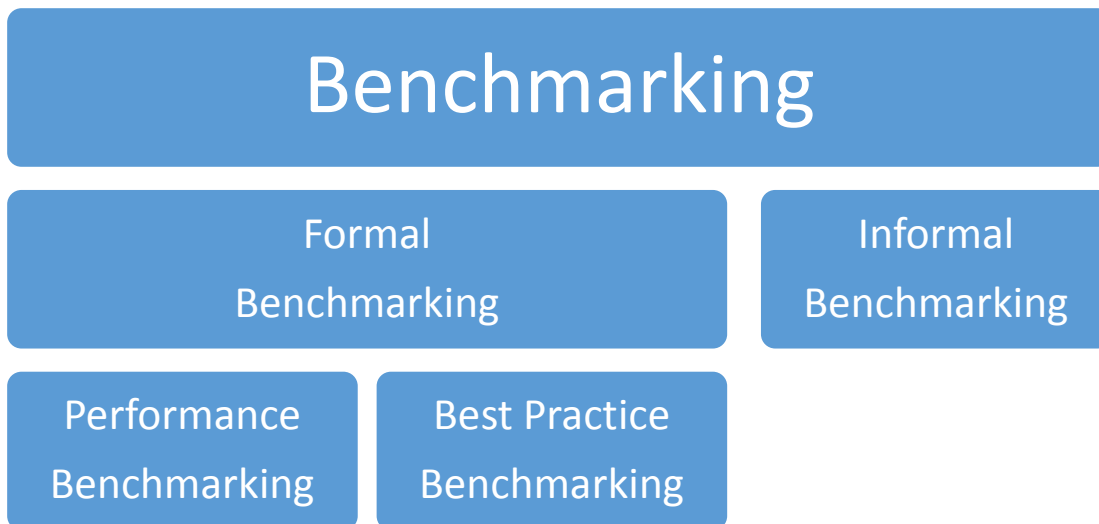


Figure 7. Benchmarking Types

Source: Mann et al. (2010)

According to Juran and De Feo (2010), benchmarking is a systematic and continuous process that facilitates the measurement and comparison of performance and the identification of best practices that enable superior performance. In this definition, objects are compared only to “best” performances.

Juran and De Feo (2010) classified benchmarking in different ways of what it is that is to be benchmarked, which the benchmarking is going to involve, and how the benchmarking is to be conducted,

- Subject matter and scope (what)
- Internal and external, competitive and noncompetitive benchmarking (who)
- Data and information sources (how)

Criteria of classification can be concluded as shown in Table 5.

Table 5. Benchmark Types

Subject Matter (What)	Participants (Who)	Data Sources (How)
Functional benchmarking	Internal benchmarking	Database benchmarking
Process benchmarking	External benchmarking	Survey benchmarking
Business unit or site (location) benchmarking	Competitive benchmarking	Self-assessment benchmarking
Projects benchmarking	Noncompetitive benchmarking (same industry and cross-industry)	One-to-one benchmarking
Generic benchmarking Business excellence models		Consortium benchmarking

Source: Juran and De Feo (2010)

There are a number of key factors to conduct benchmarking,

- Scope the study and determine objectives.
- Identify and define all metrics.
- Agree on a schedule and stick to it.
- Ensure resources are available to support the benchmarking.
- Provide support to participant throughout the process.
- Validate all data.
- Normalize the data.
- Clearly and effectively report the findings.
- Enable sharing of best practices.

Juran's 7-Step Benchmarking Process[®] has two phases. The phase 1 is a positioning analysis providing the benchmarker with a comprehensive study of the relative performance of all benchmarking participants and a thorough consideration of the performance gaps to the top performing or "best in class" organization. In the second phase, people learn from the findings in phase 1, adopting and adapting best practices, and developing improvement programs to implement changes required. The procedure of benchmarking is shown in Figure 8.



Figure 8. Procedure of Benchmarking

Source: Juran and De Feo (2010)

3.5 Composite Index

Indexes are nowadays widely used in different areas to evaluate and judge the overall situation of

one specific object or a whole industry. According to the latest version of Collins Dictionary (2015), an index is

“A numerical scale by means of which variables, such as levels of the cost of living, can be compared with each other or with some base number”

The most significant character of the index is that it can be compared. People can judge things by simply looking through the magnitudes of the numbers. Indexes have been used in financial and economic market for real long time and many of the today's well-known indexes are related to stock market. The Dow Jones Industrial Average (DJIA, or the Dow) created by Charles Dow in 1896. It was designed to reflect the United States' 12 largest companies' trading situation and calculated as the average of their stocks' prices. The index now contains 30 companies and the calculation is slightly modified in order to better evaluate the whole market's dynamic (DJIA, 2015). There are similar examples such as S&P 500, NASDAQ 100, etc.

In academic research, a composite index is the method mentioned above as a measurement that uses aggregation to combine different components into a single comparable value. The composite index helps to summarize complex or multidimensional data or redundant measures.

3.5.1 Composite Indexing

Composite indexes have been used in natural or social sciences to summarize complex or multidimensional data or redundant measures. Composite indexing entails the aggregation of any number of economic, social and political indicators. Composite indexing involves four steps, i.e. selection; scaling; weighting and aggregation; and validation (McGranahan, 1972). The aforementioned steps do not necessarily to be conducted in sequence. It is like a concurrent effort and the selection of variables, scales and the weights can be adjusted in order to arrive an acceptable index.

Booyesen (2002) concluded that choices needed to be made in two issues in the selection period. The first is the nature and number of components that will make up the index. Secondly, variables that determine the selected components need to be settled. Such selection is generally based on theory, empirical analysis, pragmatism or intuitive appeal, or some combination thereof. In this step, both bivariate and multivariate statistical methods are employed to determine the selection. The bivariate analysis measures the strength of the association between all pairs of variables; multivariate analysis assesses the overall power of any collection of variables to measure any other variable (BOOYSEN, 2002).

The second step is to scale the variables. Scaling means the 'ordering (of) things in some meaningful way', e.g. labeling a thermometer as Fahrenheit did. The aim is to point out the relation among certain objects, how far apart they are and in what direction they lie relative to each other (BOOYSEN, 2002) . Some variables have already scaled and can be used in further researches. For those variables not scaled, they can be divided into two categories, nonmetric and metric, based on the type of attributes or characteristics they represent. The researcher must identify the measurement scale of each variable used, so that nonmetric data are not incorrectly used as metric data and vice

versa (Hair et al., 2014).

Nonmetric data describe differences in type or kind by indicating the presence or absence of a characteristic or property. Nominal scales assigns number as a way to label or identify subjects or objects. The numbers assigned to the objects have no quantitative meaning beyond indicating the presence or absence of the attribute or characteristic under investigation. Therefore nominal scales can only provide the number of occurrence in each class or category of the variable being studied. Ordinal scales can make the variables ordered or ranked in relation to the amount of the attribute possessed. Ordinal scales provide no measure of the actual amount or magnitude in absolute term, only the order of the values (Hair et al., 2014).

In contrast to nonmetric data, metric data are used when subjects differ in amount or degree on a particular attribute. Metrically measured variables reflect relative quantity or degree and are appropriate for attributes involving amount or magnitude. Interval scales and ratio scales provide the highest level of measurement precision, permitting nearly any mathematical operation to be performed. The only difference between interval and ratio scales is that interval scales use an arbitrary zero point, whereas ratio scales include an absolute zero point (Hair et al., 2014).

The third thing is weighing and aggregation of component variables. The aim with this step is that weights should reflect the relative importance of each of the variables. One option, though, is not to employ the weights of variables. Here the index scores are simply averages of the corresponding variables. When employing weights, there are different ways to determine, such as consulting experts and multivariate data analysis. The former one of mentioned methods is more subjective while the latter one presents a relative objective way. Different weighting systems imply different results and, given the subjectivity inherent in many of these weighting systems, no weighting system is above criticism. After the variables' scores weighted accordingly, these scores are aggregated into a composite index score. Weighting and aggregation methods will also be discussed in performance evaluation researches (BOOYSEN, 2002).

Composite indices also need to be validated. Only through continued validation and adjustment resulting from constructive debate can indexes be improved. Adjustments are effected in selection, scaling, weighting and aggregation in order to improve the quality of the final estimates (BOOYSEN, 2002).

Composite Indexing and Benchmarking

The terms “benchmarks” and “indexes” (composite index as mentioned before) are often used interchangeably, but they are actually unique terms that describe different things.

A composite index is a measurement that uses aggregation to combine different components into a single comparable value, whilst benchmark is more often a standard. Benchmarks are often in the form of indexes thus for example the overall performance of a standard object (benchmark) can be presented as a composite index integrates different aspects of performances. All indexes (composite index is a type of them) are defined by their objectives and methodologies, which together determine

their relative strengths and weaknesses. Only when they are used in the method of benchmarking, they are benchmarks.

3.5.2 Indexes in Transport Research

In recent years, indexes are used in transportation field to evaluate vehicle or an entire transport system's efficiency or sustainability.

Energy Efficiency Design Index (EEDI)

Global climate change is one of the major challenges facing the world nowadays. Among various reasons that can cause the Greenhouse Effect, the emissions of carbon dioxide (e.g. CO₂) accounts for the most significant part. The greenhouse gas emission can be produced in different reasons, in which shipping fuel consumption would generate mass of green house gases (GHGs). Therefore, reducing the GHGs from shipping attracts peoples' attention.

The Energy Efficiency Design Index (EEDI) was made mandatory by the International Maritime Organization (IMO) for new ships in 2013 in order to reduce the emission of GHGs from international shipping (ICCT, 2011). According to ICCT (2011), the regulation requires most new ships to be 10% more efficient beginning by 2015, 20% more efficient by 2020 and 30% more efficient by 2025.

The EEDI equation is illustrated below (ICCT, 2011),

$$(3.1) \ EEDI = \frac{\text{Main Engine Emissions} + \text{Auxiliary Engines Emissions} + \text{Motors Emissions}}{\text{Efficiency Technologies}}$$

In general, the EEDI calculates a vessel's energy efficiency based on a complex equation. It is the ratio of CO₂ emission and the ship's designed transport work that involves three main variables, i.e.

- vessel's emissions;
- capacity;
- speed;

The CO₂ emission takes both main/auxiliary engine missions' and shaft generators/motors' emission into consideration. It also deducts the efficient technology applied in the ship. The transport work is the product of the vessel's deadweight tonnage and its speed at designed load. The EEDI is still under refinement to widen its range of uses and adapt to new technologies and current situations. (ICCT, 2011) The lower the EEDI a vessel has, the more efficient it is.

Clean Shipping Index (CSI)

2007 in Gothenburg, Ulf Duus and Jan Ahlbom started Clean Shipping Index (CSI), which targeted to help shippers to evaluate the environmental performance of their sea transport providers. The

commissioners were regional actors in Gothenburg and the west of Sweden – but also a number of large export- and import companies of Sweden. According to the CleanShippingProject (2013),

The project developed the tool of CSI consisting of a questionnaire of 20 basic questions on environmental performance. Ships are evaluated base on levels of,

- CO2 emissions
- SOx and Particulate Matter (PM)
- NOx emissions
- Chemicals
- Water and waste control

CO2 is scored by annual data reported. Two options can be used to calculate the emission; one is Energy Efficiency Operation Indicator (EEOI) from MEPCs and the other is calculation formula from Clean Cargo Working Group. Basic information for these calculations is the cargo carried, distance travelled and the fuel consumption.

SOx and Particulate Matter (PM) are mainly calculated by the average sulphur content in fuels for main and auxiliary engines used during a calendar year. PM is also included due to the close connection between SOx and PM emissions.

NOx emission's basis is how the NOx emissions from main and auxiliary engines relate to the standards set in Revised Marpol Annex VI. Actual figures should be declared every year.

Chemicals' scoring consists several components. Attention is focused on ship's antifouling, tube stern oil, external hydraulic fluids, gear oils, boiler-/cooling water treatment, cleaning agents and refrigerants.

Water and waste control mainly score ballast water treatment, sewage/black water, garbage handling, sludge oil handling, and bilge water treatment.

Depending the level of each area, each ship can be compared and scored base on the CSI scoring system. The scoring system has five areas with a maximum total score of 150 p, as each area has maximum score of 30 p. The Clean Shipping Project equally emphasizes the importance of each area but not scientifically compare different type of emissions with exact figures. So the tool can give a hint of overall performance but must judged with reason and used as a platform for more detailed discussions.

The Clean Shipping Project gives some recommendations defining three levels of environmental performance according to the database of all inputted ships. Three colors, red, yellow and green, reflect the performance of ships, from low to high.

Port Operator Efficiency Index (POEI)

Port Operator Efficiency Index (POEI) belongs to the project, Container Port Productivity and Port policy Evaluation, hosted by the CY TUNG International Centre for Maritime Studies (ICMS, 2015).

The project aims to study the port productivity for major container ports in the world. Based on empirical studies, the project investigates the major determinants affecting shipper's choices among ports and best practices to improve port efficiency. Discrete choice models and measures to compare port performance under different policy scenarios would be developed. The results from this project should be very useful for ports to design appropriate policies. The project used the Stochastic Frontier Analysis with Cobb-Douglas production function. The inputs of the model are,

- Cargo Handling Equipment: Quay crane, Yard crane, Mobile crane, Forklifts, etc;
- Terminal Infrastructures: Number of berth, Length of quay lines, Terminal area, etc;
- Labor inputs: Working hours, number of full-time workers;
- Storage Facilities: Storage area, Reefer points.

Individual characteristics of ports are also considered, which includes,

- Terminal level: Depth of water, Number of ship calls;
- Port level: Number of operators in port, Number of terminals in port;
- Country level: GDP, Goods exports, Goods imports;
- Continental Dummies;
- Port group Dummies.

The outputs of the model are,

- Container throughput (TEUs);
- Cargo Throughput (tones);
- Vessels Arrivals/Departures;
- Ship Turn Around Time

The POEI is measured by comparing observed and optimum costs, production, and other output's forms, subject to the constraints on quantities and prices. The optimal quantity is termed frontier, which is the maximum possible output by a certain production technology over a given period time, with minimized input cost over a given set of input possibilities. The efficiency is then the distance between the observed quantity and the frontier. The efficiency index is from 0 to 1. The port will be best in efficiency when the index is 1 and lower score means worse efficiency.

3.6 Bonus-malus System

The term bonus-malus means “good-bad” in Latin. Bonus-malus system is an incentive program used for a number of business arrangements, which rewards (bonus) good performance and penalizes (malus) bad ones.

Bonus-malus system is widely introduced in third party liability automobile insurance rating. The system penalizes policyholders at fault in accidents by surcharges and reward claim-free years by discounts. The principle is that the higher the claim frequency of a policyholder, the higher the insurance costs that on average are charged to the policyholder. Under the Bonus-malus system customer tend to has a “Bonus hunger”, which lead them to self-finance an occurred small loss, instead of financing by compensation from the insurance company, in order to avoid increased future premium.

A synonym to “Bonus-malus” is “feebate”, which is a combination of “fee” and “rebate”. Originally coined in the 1990s, feebate programs have typically been used to shift buying habits in the transportation and energy sectors. Some countries use feebate system to encourage car buyers to prefer more efficient, lower emission vehicles and manufacturers. In this system, pivot point should be set to balance revenues and fees. Values (car’s emission) differ more to the point would get more bonus/malus. Periodically, the pivot point needs to be changed to reflect changing condition (German and Meszler, 2010).

In 2008, the French government set up a Bonus-malus system for car sales. In the system, a premium (bonus) is paid to purchasers of vehicles that emit less than 130g CO₂/km. The amount declines in line with emissions of CO₂/km. For example, a vehicle that emits less than 100g CO₂/km receives 1,000 Euro as bonus and a vehicle emits between 120 and 130g CO₂ receive 200 Euro. On the other hand, a tax on sale (penalty) is levied on cars that emit more than 160g CO₂/km. The amount increase in line with emission of CO₂ and varies between 200 Euro for vehicles that emit less than 165 g CO₂, and 2,600 Euro for those emit more than 250g CO₂/km. The bonus and malus have different percentage of the cars’ prices in different cars’ energy classes. Despite the A+ class electric cars (-40.6%), cars affected by the system would have -8.1% (A class) to 5.4% (G class) bonus/malus in percentage of the car price (Callonnec and Sannié, 2009).

The system had a significant impact on consumer choices. CO₂ emissions of the new French passenger car fleet decreased by 9g/km, or about 6 percent in 2008. The average engine power decreased by 5kW and vehicle mass by 32 kg in France, both are larger than any reduction since at least 1984 (German & Meszler, 2010).

3.7 Conclusion

As can be seen from literatures reviewed above, qualities can be represented in cost are basically generated from wagons’ themselves and infrastructure. Maintenance and energy consumption are part of RUs’ operation cost. Cost related to infrastructure is mainly charged by the IMs, which in

most cases in Europe are the countries' authorities. However the authorities may not charge RUs' exactly in theoretical ways. Managers may have different ways to calculate charges and some cost policy need time to carry out, for example, noise.

Efficiency is normally evaluated by comparison of real value and optimum value. Benchmarking is sometimes used as a quality improvement method but here it is used as a method to further use the proposed index. Various studies have been conducted within rail freight industry and some of them focus on efficiency. However few of previous researches take wagons as research object. In this point, representing wagon's qualities comprehensively in cost can be meaningful. One option to use the index is in a Bonus-malus system, in which good performed wagons can be encouraged.

4 Cost Calculations

There are mainly two categories of approaches when calculating wagon's costs. The first category is called bottom-up approaches. In this category, models are used to estimate costs caused by traffic (Odolinski et al., 2014). Costs could be calculated for a base case and the marginal cost of a particular vehicle could also be calculated. In this category, the costs depend on the unit costs are used and the validity of models. In this case, the sum of individual vehicle charges may not be equal to the total cost for the network (Tunna et al., 2007).

The alternative is called top-down category. In top-down methods, formulae are used to calculate costs caused by an individual vehicle. The method to calculate costs of each wagon is by calibrating the total expenditure of the whole network with the total volume transported.

In this section, four types of costs are discussed, which are infrastructure cost, energy cost, maintenance cost and noise cost. The methods collected to calculate the costs are mostly bottom-up methods, which can better reflect the costs in relation with wagon's characteristics. Due to the limitation of relevant researches, the calculation of maintenance cost applied a life cycle cost method, which is more calculated in a macro way as a top-down approach, reflecting little information of maintenance cost's relation with wagon's features.

After each part, one example of the practice of each cost is given. The infrastructure cost, energy cost and maintenance are correlated with the real situation in Sweden. The noise cost is explained with the examples of Switzerland and Netherlands.

4.1 Infrastructure Cost

IMs charge RUs track access fees for infrastructure maintenance and operation, in which the infrastructure (track and structure) maintenance charge is differentiated by number of wagons or tonnes. There are different approaches to determine rail infrastructure charges. Marginal cost is used as the basic to decide infrastructure manager's tariff. The marginal cost is the cost incurred by running one extra wagon or wagon tonne on the tracks.

4.1.1 Damages

In this part, three kinds of damages are discussed. The damage was quantified in units as equivalent damages. The final cost of each equivalent damage should be calculated in different contexts. Then the cost of infrastructure could be calculated.

Track Damage

One popular methodology for track has been used is based on the British Rail Research, Mini-MARPAS track deterioration models. This is a bottom-up method but formulae used in top-down approaches to calculate damage are still based on the Mini-MARPAS models (Broomhead et al., 1999).

The British infrastructure manager, the Network Rail, used the following formula to calculate the Equivalent Track Damage (ETD) for track related costs.

$$(4.1) \quad ETD = C_t A^{0.49} S^{0.64} USM^{0.19} GTM$$

Where C_t is 0.89 for loco-hauled passenger stock and multiple units, and 1 for all other vehicles, A is the axle load in tonnes, S is the operating speed in miles/hour and USM is the unsprung mass (the mass of the axle wheels and axle boxes) in kg/axle.

The gross tonne mile is,

$$(4.2) \quad GTM = A \times \text{number of axles} \times \text{miles operated}$$

According to the review to the Britain's Office of the Rail Regulator (ORR, 1999), this method for track costs makes several simplifying assumptions that ignore the effects of,

- Tangential wheel-rail forces generated in curving.
- Wheel flats and out-of-roundness.
- Axle spacing.
- The design of vehicle's secondary suspension.
- Lateral forces and the shift in vertical forces due to cant deficiency in curves.

Structure Damage

The same method is also used for the cost of structures, except a different formula for damage is used. The Equivalent Structures Damage (ESD) is,

$$(4.3) \quad ESD = C_t A^{3.83} S^{1.52} GTM$$

Where C_t is 1.20 for two-axle freight wagons, and 1 for all other vehicles, A is the axle load in tonnes and S is the operating speed in miles/hour. In this equation it can be seen that the axle load and speed exponents are higher for structures when comparing to track damage. The unsprung mass term (USM) is not included in this formula. This is because the forces from unsprung mass are attenuated by bridge superstructure before they reach the bridge structure and cause damage (Tunna et al., 2007).

Rail Surface Damage

In 2007, the TTCI proposed a new model called AEA that calculates costs of rail grinding and ongoing rail renewal. The rail surface damage is a function of the tangential forces (T) and creepages (γ) between the wheel and the rail (Burstow, 2003).

A new term, wear index $T\gamma$, is the combination of lateral and longitudinal forces (T_{lat} and T_{long}) and creepages (γ_{lat} and γ_{long}) as defined in equation

$$(4.4) \quad T\gamma = T_{lat}\gamma_{lat} + T_{long}\gamma_{long}$$

The wear index $T\gamma$ has two types of influences on crack damage and wear damage. With respect to the index in different ranges, the wagon lead to different types of damages. The Figure 9 quantified the damage and shows the two components separately.

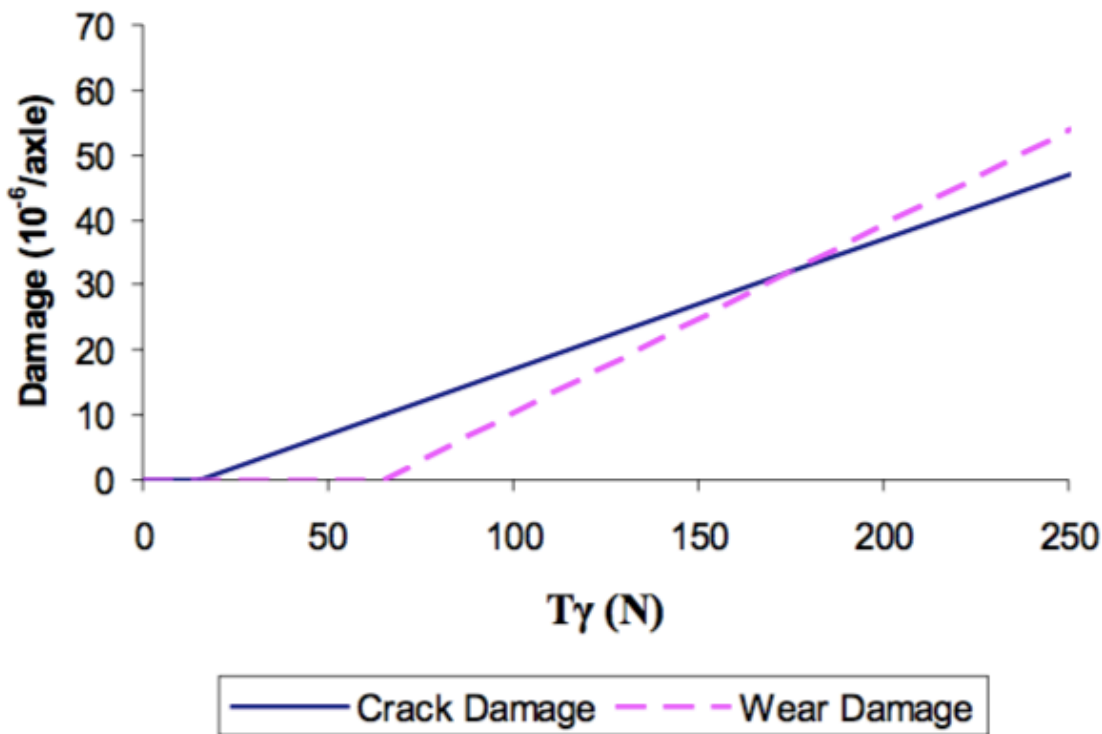


Figure 9. Crack Damage and Wear Damage in AEA model.

Source: Burstow (2003)

In the two types of damages, crack damage would lead to grinding cost and wear damage to renewal cost. In different ranges of wear index, the rail surface damage costs are,

- For $0 < T\gamma \leq 15\text{N}$, there is no grinding or renewal cost.
- For $15 < T\gamma \leq 65\text{N}$, there starts to be grinding costs to remove cracks. The grinding cost is proportional to the crack damage.
- For $65 < T\gamma \leq 175\text{N}$, there starts to be renewal costs. The grinding cost is less required as some

of the cracks are removed by wear. Grinding and wear combine to remove material from the rail and finally it requires renewal.

- For $T\gamma > 175N$, grinding is no longer required and the wear removes all the cracks. Finally the wear reach the point where a renewal is required.

Base on the wear index generated by different wagons, the function $f(T\gamma)$ is the cost relating to wagons. Parameters of the function are based on specific situations in different contexts.

In the AEA model, the function depends on the curving performance of a vehicle and cannot be expressed as a simple relationship with vehicle characteristics. The function of Equivalent Rail Surface Damage (ERSD) is,

$$(4.5) \quad ERSD = f(T\gamma)VM$$

The VM is the miles travelled by a vehicle. The $T\gamma$ is determined by computer models in different combinations of wagon types and curve radius.

4.1.2 Practice in Sweden

In Sweden, the track charge is levied per gross tonne-km and is differentiated to reflect different wagon's wear and tear characteristics. The charge level is based on STAX (maximum admissible axle load) (Trafikverket, 2015).

The track charge of freight traffic is shown in Table 6.

Table 6. Track Charge of Freight Traffic.

STAX (tonne)	Charge (SEK/Gross tkm)
≤ 22.5	0.0062
$> 22.5, \leq 25$	0.0068
> 25	0.0074

Source: Trafikverket (2015)

4.2 Energy Cost

Energy needed to carry the wagons can be calculated when knowing its resistance forces and operation speed. When accelerate and hold the whole train in a constant velocity, the tractive force equals to its resistance force. As tractive power can be transformed as the product of tractive force and velocity, so it is important to know the resistance forces. When knowing the power price per capita, the cost of energy per wagon can be calculated as,

$$(4.6) \quad C = WP$$

$$(4.7) \quad W = FVT$$

C is the cost of energy, W the work needed to operate the wagon, F the tractive power to the wagon, V the velocity, T the time in operation. When V is constant, F equals to the sum of a wagon's resistance forces.

5 main resistance forces are concluded and calculated in this section, which includes rolling resistance, aerodynamic resistance, grade resistance, curve resistance and acceleration resistance. Other resistance forces such as tunnel resistance are relatively small thus not discussed. Some resistances calculated below has the whole train as target object, the validity to adapt such calculations to specific wagon is questionable. In these cases, a single wagon's energy cost may need to be averaged as a part of the whole train in further calculations.

4.2.1 Resistance Forces

Rolling Resistance

Under the term rolling resistance there are several kinds from different parts of the vehicle. It includes rolling resistance, slide resistance, roller bearing resistance and dynamic resistance (Wende, 2003).

According to Wende (2003), the rolling resistance force is,

$$(4.8) \quad F_{W0Z} = f_{W0Z}G_z$$

in which,

f_{W0Z} Parameter to rolling resistance (train) in ‰

G_z Downward force (train) in N

$$(4.9) \quad f_{W0Z} = C_{0Z} + C_{1Z} \left(\frac{v}{v_{00}} \right) + C_{2Z} \left(\frac{v}{v_{00}} \right)^2$$

in which,

v Velocity in m/s

$v_{00} = 27.78m/s$ Velocity constant in m/s

$C_{1Z} = 0.5‰$ Constant to f_{W0Z} in ‰

$C_{2Z} = 0.6‰$ Constant to f_{W0Z} in ‰

C_{0Z} Constant to f_{W0Z} in ‰

$$(4.10) \quad C_{0Z} = \frac{f_{WAL}G_L + \left(c_{AW} + \frac{F_A}{G_A}\right)G_W}{G_Z}$$

in which,

$f_{WAL} = 3.5\%$ Parameter to starting resistance in ‰

$c_{AW} = 0.6\%$ Constant in ‰

$F_A = 100N$ Axle load constant in N

G_A Axle load in kN

G_L Downward force (loco) in N

G_W Downward force (set of wagons) in N

From the calculation, it can be seen that the rolling resistance force correlates positively with the mass of train rises, but correlates negatively with the axle load. This indicates that, when carrying same weight of cargo, wagon with less dead weight and number of axles could lead to less rolling resistance.

Aerodynamic Resistance

Aerodynamic resistance is referred to the forces that are caused through exterior contact of air with the vehicle. It includes turbulence forces, surface friction forces, compressive force at the first car of a train, suction force at the last car and gap forces between cars.

Aerodynamic resistance is calculated by the ‘‘Hannoversche Formel’’ (VoG et al., 1972), where,

$$(4.11) \quad F_{WLuZ} = 0.5\rho_{norm}c_{w-Gesamt}A_{norm}v_F^2$$

$$(4.12) \quad c_{w-Gesamt} = c_{w-Lok} + \sum c_{w-Wagen}$$

in which,

F_{WLuZ} Aerodynamic resistance force (train) in N

$c_{w-Gesamt}$ Air drag coefficient (train)

c_{w-Lok} Air drag coefficient (loco)

$c_{w-Wagen}$ Air drag coefficient (wagon)

$\rho_{norm} = 1.225kg/m^3$ Normative air density

v_F Velocity

$A_{norm} = 10 m^2$ Front surface

Though further researches are required, according to Vollmer (1989), air drag coefficients can be estimated by following formula,

$$(4.13) \quad c_{w-Wagen} = 10^{-6}c_{Gruppe}M^2 \frac{A_{Mod}}{A_{Orig}}$$

in which,

$c_{w-Wagen}$	Air drag coefficient (wagon)
c_{Gruppe}	Factor of $c_{w-Wagen}$
$M = 32$	Experimental model factor
$A_{Mod} = 1m^2$	Front surface of model
$A_{Orig} = 10m^2$	Front surface of wagon

c_{Gruppe} is a factor of $c_{w-Wagen}$ that can be calculated with the wagon's length and gap influence.

The aerodynamic resistance is positively correlates to the number of wagons and the length of each wagon. More gaps on the train, not matter between each two wagons or on wagons themselves, could also lead to more aerodynamic resistance.

Grade Resistance

The grade resistance is caused by the component force of gravity, which is horizontal to track. The resistance is positive when running upgrade and negative when downgrade. Only positive resistance is discussed in this section. Negative resistance may lead to problems such as reaching speed limit but such influences are not calculated.

$$(4.14) \quad F_N = G_Z \sin \theta$$

in which,

F_N	Grade resistance in N
G_Z	Weight force (train) in N
θ	Gradient

The grade resistance is positively correlated with the gradient and weight of the train/wagon.

Curve Resistance

Curve resistance is a sum of different movements, which are caused when train runs in curved track. It consists of transverse movements, rotary movements and longitudinal movements.

Curve resistance can be calculated with the help of methods from Schramm (1963),

$$(4.15) \quad F_{Bo} = f_{Bo} G_Z$$

in which,

F_{Bo}	Curve resistance (train) in N
f_{Bo}	Parameter to curve resistance (train) in ‰
G_Z	Weight force (train) in N

$$(4.16) \quad f_{Bo} = 1000 \frac{\mu_R}{2R} (1 + \mu_{Sp} \tan(\beta)) \left(\sqrt{p^2 + \left(\frac{e}{2}\right)^2} + \sqrt{(a-p)^2 + \left(\frac{e}{2}\right)^2} \right)$$

in which,

R	Curve radius in m
$\mu_{Sp} = 0.225$	Friction factor flange/rail
$\mu_R = 0.225$	Friction factor wheel/rail
β	Edge decline of flange
p	Distance interpole/front bogie in m
e	Distance of rolling circle in m
a	Distance of axes in bogie in m

The curve resistance is mainly decided by the curve radius and the mass of the train.

Acceleration Resistance

Acceleration resistance only occurs when accelerating the vehicle on higher velocities. When accelerating the train, there is extra force needed to accelerate rotating masses and this extra force is included by considering a higher train mass using a mass factor. The factor can be calculated with,

$$(4.17) \quad \psi = \frac{m_{DZ} + m_Z}{m_Z}$$

$$(4.18) \quad m_{DZ} = z_T m_{DT} + z_W m_{DW}$$

in which,

ψ	Mass factor
m_{DZ}	Rotating mass (train) in t
m_Z	Mass (train) in t
z_T	Number of powered axles (loco)
$m_{DT} = 4.0t$	Rotating mass powered axle (electric axles) in t
z_W	Number of unpowered axles (freight wagon)
$m_{DW} = 0.6t$	Rotating mass u powered axle (freight wagon) in t

Acceleration resistance force,

$$(4.19) \quad F_a = \psi m_Z a$$

in which,

F_a	Acceleration resistance force in N
ψ	Mass factor
m_Z	Mass (train) in kg
a	Current acceleration in m/s ²

The calculation shows that the mass of train and number of axles are positively correlated with the acceleration resistance.

4.2.2 Practice in Sweden

In practice, most IMs charge base on locomotives' usage. For electrified engines, some locomotives have meter set on them. The meter set by Swedish Transport Administration (Trafikverket) has time resolution and GPS, and it is therefore possible to read the time and place of electricity consumption. The Swedish Transport Administration will charge the RUs that have the Administration's meter hourly with the amount of the current electricity price including network charges for each electricity area (Trafikverket, 2015).

For those locomotives with their own meters or without meter, their undertakings need to report the usages to Swedish Transport Administration monthly. The authority has template of each type vehicle's energy consumption in different period of time (due to the weather). The price of energy provision (per kwh) is based on electricity price, network cost, certificate and a loss surcharge varies to different types of vehicles (Trafikverket, 2015).

For diesel engines, Swedish Transport Administration charges an emission cost. RUs would not purchase fuel from the authorities but need to report the usage to them. This charge is based on the usage and differentiated by the engine's type.

4.3 Maintenance

In this section, maintenance cost model is proposed, which is based on LCC model formulated in Palo (2014). Additionally, the wagon maintenance in workshop has been studied based on the interview and field research in SweMaint AB workshop in Gothenburg.

Wheel maintenance is the principal part in the overall rolling stock maintenance. The wheels maintenance constitutes a large part of a railway's rolling stock maintenance cost and the interface between wheel and rail has the greatest influence on maintenance costs for the train-track system (Palo et al., 2012). Therefore, only the wheel maintenance cost is considered when estimating the overall maintenance cost in this research.

In order to estimate wheel maintenance cost, some theoretical approaches have been investigated. Considering the situation that the purchasing of rolling stock asset is a long-term investment, it is therefore that life cycle cost (LCC) can be applied for the rolling stock maintenance, as it is one of the most effective cost approaches when buying assets for the long term (Jun and Kim, 2007). In this research, the authors have applied the LCC model for the rolling wheels maintenance cost estimation and the details of LCC is further investigated in the following part.

4.3.1 Life Cycle Cost

Life cycle cost (LCC) is a method to identify cost drivers and to collect the cost data of a system, module or component over its whole lifetime (Ekberg and Paulsson, 2010). Palo et al. (2012) and Palo (2014) have formulated a LCC model for the rolling wheel maintenance cost estimation, which can be applied in this research.

According to Palo et al. (2012), a basic LCC model for rail wagon wheels maintenance has been established. The model is as illustrated below, i.e.

$$(4.20) \quad LCC = C_A + C_I + C_{PM} + C_{CM} + C_R$$

Where C_A is the acquisition cost, which represents the purchasing and installation of new wheels sets. C_I is the inspection cost. C_{PM} is the preventive maintenance cost while C_{CM} is the corrective maintenance cost. C_R is the risk/safety cost.

In the following research, Palo (2014) has further improved the LCC model for rail freight wheels maintenance. The total cost for rail freight wheels maintenance C_{TOT} is as illustrated, i.e.

$$(4.21) \quad C_{TOT} = C_t + C_d + C_i + C_r + C_{re}$$

Where C_t is the wheel turning cost. C_d is the wheel downtime cost. C_i is the inspection cost. C_r is the risk cost. C_{re} is the replacement cost for worn out wheels. More specifically, each cost function are illustrated below, respectively. The following mathematic model and equations are used directly from Palo (2014).

C_t represents the wheel turning cost per year which is given by,

$$(4.22) \quad C_t = \left\{ \sum_{i=1}^{N-1} \frac{t * n_{L_i}}{(1+r)^i} \right\} * \frac{r}{1 - \frac{r}{(1+r)^N}}$$

Where t is the cost of turning the wheel to maintenance workshop per time. n_{L_i} is the number of turning events for i^{th} wheel of the whole wheel systems. N is the total number of turning periods up to the safety wear limit for renewal. r is the discounting rate.

C_d denotes the wheel downtime cost which is given by,

$$(4.23) \quad C_d = \left\{ \sum_{i=1}^{N-1} \frac{n_{L_i} * h_{DT} * d}{(1+r)^i} \right\} * \frac{r}{1 - \frac{r}{(1+r)^N}}$$

Where h_{DT} is the expected downtime due to each turning of the wheel. d is the expected cost of

downtime per hour. n_{L_i} is the number of turning events for i^{th} wheel of the whole wheel systems. r is the discounting rate.

C_i denotes the annual inspection cost which is given by,

$$(4.24) \quad C_i = C_{i_y} + C_{i_w}$$

Where C_{i_y} and C_{i_w} represent the inspection cost in the railway yard and in the wayside, respectively.

$$(4.25) \quad C_{i_y} = \left\{ \sum_{i=1}^{N_{I_y}} \frac{i_c}{(1+r_j)^i} \right\} * \frac{r}{1-\frac{r}{(1+r)^N}}$$

$$(4.26) \quad C_{i_w} = \left\{ \sum_{i=1}^{N_{I_w}} \frac{i_c}{(1+r_j)^i} \right\} * \frac{r}{1-\frac{r}{(1+r)^N}}$$

Where i_c is the cost of each inspection. r_j is the discounting rate relating to the interval of inspection. N is the total number of turning periods up to the safety wear limit for renewal. N_{I_y} and N_{I_w} are the integral functions which can be illustrated as below, i.e.

$$N_{I_y} = \text{Integar} \left[\frac{M_N}{I_{f_y}} \right];$$

$$N_{I_w} = \text{Integar} \left[\frac{M_N}{I_{f_w}} \right];$$

Where I_{f_y} and I_{f_w} are the numbers of inspection times per wheel-set in the railway yard and wayside, respectively. M_N is the total accumulated km over the period N .

C_r denotes the risk cost which is given by,

$$(4.27) \quad C_r = \left\{ \frac{\sum_{i=0}^N E[N(M_{i+1}, M_i)] * [P_i(B) * k + (1 - P_i(B) * P_i(A)) * a + (1 - P_i(A)) * \bar{C}]}{(1+r)^i} \right\} * \frac{r}{1-\frac{r}{(1+r)^N}}$$

Where $E[N(M_{i+1}, M_i)]$ is the expected number of failures over the period i and $(i + 1)$. $P_i(B)$ is the probability of detecting potential wheel failures using the manual inspection. $P_i(A)$ is the probability of undetected potential wheel failures leading to rail accidents. k is the expected cost of repairing detected wheel failures. a is the expected cost per derailment. \bar{C} is the expected cost of each wheel failure repair on emergency basis.

$P_i(A)$ and $P_i(B)$ are generally based on three parameters, i.e.

- n_{NDT_i} , which represents the number of detected potential wheel failures by manual inspections in period i .
- n_{RB_i} , which represents the number of wheel failures between two manual inspections in period i .
- n_{A_i} , which represents the number of accidents in period i .

Finally, C_{re} denotes the expected cost of replacement for wheels which is given by,

$$(4.28) \quad C_{re} = I * \frac{r}{1 - \frac{1}{(1+r)^N}}$$

Where I is the annual cost of investment in new wheels. r is the discounting rate.

Generally, the LCC model in Palo (2014) includes complicated factors, i.e. wheel turning, downtime loss, inspections (both in railway yard and wayside), rectification (based on manual inspections), repair, derailments and replacement. In this research, the authors have applied this model for the rolling wheel maintenance cost estimation and the total cost evaluation.

4.3.2 Practice in SweMaint

In order to better understand the wagon maintenance procedure, the authors have conducted an interview with the technical support officer in SweMaint workshop, Gothenburg, which is the leading supplier of maintenance and repair services for owners and RUs of rail freight wagon in northern Europe. According to their feedback, the authors have got a better understanding of wagon maintenance practice.

In the SweMaint maintenance workshop, the current charges for wagon maintenance are activity-based. More precisely, RUs send the problematic vehicles to the workshop. Activities associated with inspection, repair and replacement are done in designed working areas. Then, the workshop would send invoices to RUs which include list of activities that they have done for the wagons. The total maintenance charges are base on these activities and different maintenance activities have different charges which are cost-based. Unfortunately, the authors cannot get the access to the maintenance tariff in their workshop. However, the workshop only concerns the problematic vehicle maintenance, but they do not know the real operation procedures that cause the wagon failures.

4.4 Noise Cost

In this section, the noise cost model is proposed, which is based on the noise marginal cost model formulated in Andersson and Ögren (2007) and (2013). The NDTAC and its implementation in

Europe are also investigated.

The objective of charging approaches is to penalize RUs that do not apply quiet wagons and technologies. These approaches employ the short run marginal cost (SRMC) approach by estimating the total number of people affected by rail noise. These approaches apply factors either used in national appraisal guidelines or derived from previous studies. The final costs are assigned to different train types (e.g. passenger train and freight train) per train km (Andersson and Ögren, 2007). Additionally, these approaches concentrate in more detail on the number of people being exposed to rail noise. Some typical factors have been identified, e.g. differentiation in time period differentiation in route types; differentiation in the distribution of affected population (by classifying sound pressure level classes) (Distefano et al., 2007).

4.4.1 Short Run Marginal Cost (SRMC)

It has been decided that infrastructure charges in EU should be based on short run marginal cost (SRMC) principle (EC, 1998). In this section, the SRMC model for railway-noise charges has been deduced based on Andersson and Ögren (2007), (2013).

According to Andersson and Ögren (2007), (2013), the total social noise cost of railway traffic can be illustrated as, i.e.

$$(4.29) \quad S(Q) = \int_0^{\infty} C(L(Q, r, X)) * n(r) dr$$

Where $S(Q)$ is the total social noise cost. $C(L(Q, r, X))$ is the cost-function of the noise level L , which is assumed to be determined by the traffic volume (Q), distance to the noise emission source (r) and other factors (X) that could influence the noise level. $n(r)$ is the density of exposed individuals at different distance.

Based on this, the marginal social cost with respect to traffic volume can be described as, i.e.

$$(4.30) \quad M(Q) = \frac{\partial S(Q)}{\partial Q} = \int_0^{\infty} \frac{\partial C(L(Q, r, X))}{\partial L} * \frac{\partial L(Q, r, X)}{\partial Q} n(r) dr$$

Where marginal cost $M(Q)$ is the change in total cost $S(Q)$ as a result of a change in traffic volume (Q). However, as discussed in Andersson and Ögren (2007) and (2013), data on individual distribution are often available in discrete forms. Therefore, the distance (r) is divided into i discrete intervals, which the noise level (L) is equal for all individuals in the same intervals. Then, marginal cost can be estimated as, i.e.

$$(4.31) \quad M(Q) = \sum_i \int_{a(i)}^{b(i)} \frac{\partial C(L(Q, r, X))}{\partial L} * \frac{\partial L(Q, r, X)}{\partial Q} n(r) dr$$

Where $a(i)$ and $b(i)$ are the boundaries for interval i . However, in practice, the noise level is

available in discrete forms, e.g. data on noise levels in Environmental Noise Directive has been collected in 5 dB intervals (EC, 2002). Therefore, the marginal cost can be written as,

$$(4.32) \quad M(Q) = \sum_i \frac{\partial c(L(Q,r,x))}{\partial L} N(L) \Delta L$$

Where ΔL is the change in noise level caused by traffic, i.e. $\Delta L = \frac{\partial L(Q,r,x)}{\partial Q}$. $N(L)$ is the number of exposed individuals to the noise level L , $N(L) = n(r) \Delta r$. $C(L)$ is the cost function, $C(L) = \frac{\partial c(L(Q,r,x))}{\partial L}$. Then the railway-noise charges based on the SRMC principle can be estimated as, i.e.

$$(4.33) \quad T(Q) = \sum_L C(L) N(L) \Delta L$$

Where $T(Q)$ is the total railway noise charges. It is formulated by multiplying the marginal cost $M(Q)$ with the change in traffic volume ΔQ , i.e. $T(Q) = M(Q) * \Delta Q$.

In this equation, there are three variables, i.e.

- $C(L)$ is the individual marginal cost function.
- $N(L)$ is the number of inhabitants exposed by noise level L .
- ΔL is the change in sound level due to the marginal train.

$C(L)$ function is the main issue in the final equation, which shows the association between noise level and the marginal cost per year and inhabitant. Andersson and Ögren (2007) formulated the cost function and fitted a monotonic polynomial by using the official cost estimates in SIKKA (Updated data is not available as the Institution has been out of operation), i.e.

$$(4.34) \quad C(x) = 31.712 + 6.1563x + 0.88402x^2 + 0.032610x^3 - 0.0010994x^4$$

Where $x = L_{AEq,24h} - 62$, $L_{AEq,24h} \in [50,75]$.

The noise level can be calculated by different methods, e.g. Nordic method (Jonasson and Nielsen, 1996). The Nordic method describes how to calculate the noise level by using the data on, i.e. rail roughness, traffic flow and speed. Some noise indicators that can represent the noise level is introduced in the following part.

4.4.2 Noise Indicators

In order to measure the noise level L , some common noise indicators have been identified, i.e. $L_{AEq,24h}$ and L_{DEN} (Andersson and Ögren, 2007). They are introduced respectively.

$L_{AEq,24h}$ denotes the noise equivalent level for a 24-h period with the unit dB (Andersson and Ögren, 2007). The equivalent level is an energy average over a certain time period and it is often used as an

indicator of general annoyance (Sandberg and Ejsmont, 2002). Compared to $L_{AEq,24h}$, L_{DEN} (day-evening-night) is another common noise indicator employed in the Environmental Noise Directive (EC, 2004). L_{DEN} is an equivalent level focusing on the noise events during the evening and night time, which gives more weight to evening and night time traffic (Miedema and Oudshoorn, 2001).

According to Miedema and Oudshoorn (2001), L_{DEN} establishes a penalty function for the night time traffic and the function is illustrated as, i.e.

$$(4.35) \quad L_{DEN} = 10 \log \left(\frac{12}{24} * 10^{0.1 * L_d} + \frac{4}{24} * 10^{0.1 * (L_e + 5)} + \frac{8}{24} * 10^{0.1 * (L_n + 10)} \right)$$

Where L_d is the sound level for day time traffic, L_e is the sound level for evening time and L_n is the sound level for night time traffic. As shown in this function, the evening noise level is applied a 5 dB penalty and the night noise level has is applied a 10 dB penalty. Therefore, it is possible to differentiate the SRMC for three time periods by applying L_{DEN} indicator (Andersson and Ögren, 2007).

4.4.3 NDTAC

Noise differentiated track access charge, namely NDTAC, which is proposed by EC, is a coordinated approach to incentivize EU members to retrofit freight wagons at European Level. Generally, three theoretical approaches towards the implementation of NDTAC at academic level have been discussed in this section (KCW, 2009).

Rolling Stock Type Differentiated Access Charges

In this system, RU classifies all their wagons into two types, i.e. Low-Noise (LN) wagons and Non Low-Noise (NLN) wagons. The basic assumption is that the noise emissions can be estimated as a function of the number of trains and their composition in terms of LN and NLN wagons. IMs verify all vehicles when they pass by predefined cordons and grant a bonus to RUs if they run the LN wagons.

Emission Ceiling Bonus-malus System

This system is based on the measurement of real time noise emissions. The real noise emissions level of each wagon is measured by measurement stations which are installed along the railway network. In this system, the noise ceilings have been predefined and fixed for each measurement stations. These stations grant a bonus for wagons that do not exceed the predefined ceilings and charge a malus for the wagons which exceed the predefined ceilings.

TSI Bonus-malus System

Different from the Emission Ceiling Bonus-malus System, this system is based on the measurement of theoretical noise emissions. This system applies the predefined noise emission ceilings in the TSI

noise. Although the TSI regulation is only for new wagons, its scope can be expanded to all wagons. The mechanism of bonus and malus is similar to the aforementioned Emission Ceiling Bonus-malus System. However, this system requires the certification of old wagons according to the TSI noise. IMs either grant a bonus for wagons with certifications or charge a malus for wagons without certifications.

Based on these, two design options for the implementation of NDTAC have been defined in the previous report (KCW, 2009). Main factors of these options are described briefly in the following section.

Pass-by NDTAC

This option is based on the Emission Ceiling Bonus-malus System approach. The real noise is received by measurement stations installed along the railway routes. The real noise is relevant to the bonus and malus. A bonus is granted to trains which do not exceed the predefined noise levels and a malus is charged to trains which exceed the certain noise levels. In this option, the basic charging unit is the entire train rather than individual wagons. Therefore, wagons do not need to be recorded separately. If the noise level of entire train is considered ‘silent’, the rectifications of old wagons are necessary. Finally, RUs and participating WOs/WKs have to allocate the received bonus to involved stakeholders.

TSI Noise-based Rolling Stock Differentiated NDTAC

This option is based on the TSI Bonus-malus System approach. In order to implement this option, all wagons are required to get the homologation on the basis of TSI noise. Different from the Pass-by NDTAC, the charging unit in this option is the number of axles rather than the entire train. Therefore, wagons need to be recorded separately for the allocation of the bonus. Finally, RUs have to allocate the received bonus to WKs/WOs.

The main characteristics of these two options are shown in Table 7.

Table 7. Main Characteristics of Design Options

Pass-by NDTAC	TSI Noise-based NDTAC
Train based;	Axle based;
Real noise is relevant for bonus;	Homologation of wagon on basis of the TSI Noise;
Concerning pass-by noise no technical solution can be preferred;	Design of bonus can prefer technical option by design of NDTAC;
Homologation after retrofitting/modernization mandatory;	Homologation after retrofitting/modernization mandatory;
Retrofitting/modernization of old wagons not necessary if entire train is silent;	Retrofitting/modernization of old wagons necessary, otherwise no bonus;

Source: KCW (2009)

4.4.4 Practice of NDTAC in Europe

This section introduces the implementation of NDTAC in Europe countries by the case in Switzerland and Netherlands. The Switzerland and Netherlands are the only two countries in Europe which have implemented a bonus for low noise railway vehicles on national legislation level (Oertli and Hübner, 2010). Other countries such as Austria, have discussed the possibility of implementation of noise-related track access charges.

UIC has established the report on current status of noise-related track access charges in EU countries in 2008, 2009 and 2010. The following part is based on these UIC reports.

Switzerland

Switzerland has implemented a comprehensive program of noise reduction measures since 2001. In this program, all Swiss railway vehicles are required to convert to low-noise systems. In order to support this program, Swiss legislation on railway noise abatement stipulates that all railway vehicles that meet the new noise standards would be awarded with bonus. The noise bonus mainly encourages foreign wagon owners to retrofit their rolling stocks. Therefore, only foreign wagon owners are eligible to apply for the bonus, domestic wagon owners are compensated as part of the Swiss noise abatement program via a direct funding scheme (Hübner, 2009).

During the practical implementation procedure, the RU should submit a detailed application to the Federal Office of Transport (FOT) for the bonus. The application should state the type of vehicle, actual sound levels and travelled distance. Whether and how the RUs have to pass the bonus they receive on to the wagon owners is not specified (Hübner, 2008). The bonus unit is 'per axle km' and the data can be obtained from the databases in Cargo Information System, which are accessed to both the RUs and IMs. The RUs directly benefit from the bonus and the refund incentivizes them to use low-noise railway vehicles (Hübner, 2009).

Netherlands

Similar to Switzerland, a noise-related bonus scheme has been implemented from 2008 in Netherlands. Only vehicles which have been retrofitted with low-noise system would benefit from the bonus and new vehicles with low-noise technology are excluded. The bonus unit is based on 'per vehicle km'. More specifically, the bonus is fixed at 0.04 Euro/wagon-km for both passenger and freight vehicles. The total bonus is limited to 4800 Euro/vehicle for both passenger vehicle and freight wagon (based on a maximum mileage of 120,000 km over 2 years) (Hübner, 2009).

The bonus has to be granted following self-declaration by RUs in Netherlands. By March 2009, only two passenger-operators had accepted the bonus system no freight operators had accepted the bonus system (Hübner, 2009).

5 INDEX CONSTRUCTION

In this section, the Rail Quality Based Index is proposed. The index consists four types of costs as discussed in the fourth section. All the costs are calculated in the time period of one year. The formulas to calculate the costs are reformed with uniform parameters.

5.1 Assumption

The index proposed would sum up all the aforementioned costs as a total cost. The total cost would consist of infrastructure cost, energy cost, maintenance cost and cost of noise. All those sub-costs contained could be differentiated by the wagons' characteristics and can be used to reflect the wagons' performance. The purpose to divide the total cost with wagon's loading capacity and mileage is to represent the wagon's efficiency. The reason to use the loading capacity is because in most cases the gross weights would direct influence most of the costs and the loading weight is only a part of them, some light deadweight wagons could not show their advantages when only considering the gross weight. The real usage of the wagon's capacity is not discussed, and the weight is assumed to allocate equally on wagon's axles.

The index also includes a quotient of the wagon's length and loading capacity. The assumption here is that stakeholders would prefer shorter wagons when the loading capacities are same.

The costs discussed in the index are all calculated in years. To simplify the calculation, all costs are assumed to happen in the beginning of each year, and it goes the same to the maintenance operations. In the maintenance cost, only wheel maintenance cost is calculated to represent all maintenance costs.

Object of calculation in the index is each single freight wagon. This means the sub-costs are all in each wagon's. As mentioned before, some costs need to be calculated in whole trains, for example, the noise cost and some resistance forces to calculate energy costs. Not all those methods are valid to calculate cost per wagon. So we recommend allocating the whole train's cost to each wagon. These sub-costs per wagon are averaged from the train's cost by number of wagons per train. In this way, all wagons in one train are assumed to be the same.

Not all characteristics of wagons could be used as inputs in the index. This is partly because most of them are not well quantified, e.g., type of brake system and bogie. These characteristics have their influence on the index. However, some of their influence could be got when detecting some relevant parameters. Some of them, on the other hand, are not considered in this index, such as the operation of the wagon and functional parts of the wagon.

5.2 Variables and Abbreviation

The following Table 8 shows the variables and their abbreviations, which are applied in the index equation. All these variables are divided into several categories, e.g. cost and time. Among these variables, some of them are parameters need to be detected directly.

Table 8. Variables and Abbreviations

Variables	Abbreviations
Benchmark value for infrastructure cost	BV_I
Benchmark value for energy cost	BV_{EN}
Benchmark value for maintenance cost	BV_M
Benchmark value for noise cost	BV_N
Infrastructure cost	C_I
Energy cost	C_{EN}
Maintenance cost	C_M
Noise cost	C_N
Cost of track damage	C_{It_d}
Cost of structure damage	C_{Is_d}
Cost of rail surface damage	C_{Irs_d}
Turning cost	C_{Mt}
Downtime cost	C_{Md}
Inspection cost	C_{Mi}
Inspection cost in railway yard	C_{Miy}
Inspection cost in wayside	C_{Miw}
Risk cost	C_{Mr}
Replacement cost	C_{Mre}
Wheel turning cost (per time)	$C_{Mt \cdot t}$
Downtime cost (per time)	$C_{Md \cdot d}$
Inspection cost (per time)	$C_{Mi \cdot i}$
Repair cost for detected failure (per time)	$C_{Mr \cdot rd}$
Repair cost for undetected failure leading to accident (per time)	$C_{Mr \cdot ru}$
Derailment cost (per time)	$C_{Mr \cdot d}$
Annual cost for new wheels investment	$C_{Mre \cdot ai}$
Individual marginal noise cost by noise level L	C_{Niml}
Tractive force	F_T
Resistance force	F_R
Rolling resistance	F_{Rr}
Aerodynamic resistance	F_{Rae}
Grade resistance	F_{Rg}
Curve resistance	F_{Rc}
Acceleration resistance	F_{Rac}
Length of wagon	L
Noise level	LV

Mileage	M
Number of axles	N_A
Number of turning events of all wheels in period i	N_{Ti}
Number of inspection times in railway yard	N_{Iy}
Number of inspection times in wayside	N_{Iw}
Number of inhabitants exposed by noise	N_L
Number of wheel failures in period i	N_{Fi}
Number of wagons	N_W
Price for energy (diesel and electricity)	P_e
Probability of detecting wheel failures in inspection	$Pr_{(D)}$
Probability of undetected wheel failures leading to accident	$Pr_{(U)}$
Traffic volume	Q
Discounting rate	R
Discounting rate related to inspection interval	R_i
Operation time	T_O
Downtime	T_D
Speed	V
Axle load	W_A
Max capacity	W_C
Unsprung mass	W_{UM}

5.3 Rail Quality Based Index

Based on the findings in section 4, the final index construction includes four components, i.e. infrastructure cost, energy cost, maintenance cost and noise cost. Here the authors name it Rail Quality Based Index (RQBI). The index equation is formulated as,

$$(5.1) \quad RQBI = \left(\frac{C_I + C_{EN} + C_M + C_N}{MW_C} \right) \left(\frac{L}{W_C} \right)$$

The first part of the index is the price per usage unit (tonne-km) and the second part a quotient of wagon's length (m) and max capacity (tonne). The index is a product of these two parts.

5.4 Index Components

In this section, the four index components are illustrated respectively. The data availability issue of each calculation is also discussed.

5.4.1 Infrastructure Cost

$$(5.2) \quad C_I = C_{Ita} + C_{Isd} + C_{Irsd} = \mu_{Ita} W_A^{\lambda_1} V^{\lambda_2} W_{UM}^{\lambda_3} N_A M + \mu_{Isd} W_A^{\lambda_4} V^{\lambda_5} N_A M + \mu_{Irsd} V M$$

Equation (5.2) applies the Bottem-up approach, which includes variables, i.e. axle load, speed, unsprung mass and gross tonne-km ($N_A M$). μ_{It_d} , μ_{Is_d} and μ_{Isd} are eigenvalues associated with nations and different contexts. The exponents λ_i are measurement values which are gained by parameter detection.

In the infrastructure cost, the wagon's characteristics' information such as the axle load and unsprung mass and gross tonne-km are available from the RUs and FORD system. The exponents are detected in previous research as reviewed in 4.1.1 but further researches could be done to ensure their validity. The wagon's speed could be recorded by the RUs but in fact the data is limit currently. Eigenvalues need to be detected in the future under different contexts.

5.4.2 Energy Cost

$$(5.3) \quad C_{EN} = F_T V T_O P_e$$

Where,

$$(5.4) \quad F_T = F_R = F_{Rr} + F_{Rae} + F_{Rg} + F_{Rc} + F_{Rac}$$

Equation (5.4) includes variables, i.e. tractive force, speed, operating time and energy price. The analysis of tractive force and resistance force can be seen in section 4.2.1.

The $V T_O$ is recorded by RUs in form of total distance and inputted in the FORD system. P_e is available as a part of the tariff of electricity provider. F_T needs to be discussed in different resistance forces. Some parameters are available from previous studies as illustrated in 4.2.1. F_{Rr} can be calculated with the wagon's weight and locomotive's information. Some parameters need to be detected by different types of wagon to calculate the F_{Rae} . F_{Rg} is related to the wagon's weight and track's grade condition. F_{Rc} needs information about the curve of the track. F_{Rac} is related to wagon's specific operation condition.

5.4.3 Maintenance Cost

$$(5.5) \quad C_M = C_{Mt} + C_{Md} + C_{Mi} + C_{Mr} + C_{Mre} =$$

$$\left\{ \sum_{i=1}^{N-1} \frac{N T_i (C_{Mt.t} + C_{Md} T_D) + N F_i [Pr_{(D)} C_{Mr.rd} + (1 - Pr_{(D)}) Pr_{(U)} C_{Mr.d} + (1 - Pr_{(U)}) C_{Mr.ru}]}{(1+R)^i} + \sum_{i=1}^{N I_y} \frac{C_{Miy}}{(1+R_i)^i} + \right.$$

$$\left. \sum_{i=1}^{N I_w} \frac{C_{Miw}}{(1+R_i)^i} + C_{Mre.ai} \right\} * \frac{R}{1 - \frac{1}{(1+R)^N}}$$

Equation (5.5) applies the LCC model which includes variables, i.e. wheel turning cost, downtime cost, inspection cost, risk cost and replacement cost. The unit costs applied in this equation are the expected values which can be gained by the averaging the historical data. Future values are discounted into present values in this equation.

Wagon's maintenance cost information should be available in RUs' company record. And together with the records in FORD system, a bottom-up method to relate the maintenance cost with the wagon's features could be possible. However, the availability of this cost still needs further investigation, as "the operators themselves most often do not have any good information themselves" (Floden, 2015).

5.4.4 Noise Cost

$$(5.6) \quad C_N = \frac{\sum_L C_{Niml} N_L \Delta Lv}{N_W}$$

Equation (5.6) applies the short run marginal cost (SRMC) approach which includes variables, i.e. individual annual marginal cost, noise level and the number of wagons. Noise level is a measurement value, which is gained by the noise receiver points along the railway route.

C_{Niml} is based on the regional context. N_L and ΔLv is varied by wagon's type and track condition. N_W could be available as part of RUs' record and data in FORD system.

6 Implementation

This section includes a planning design of the usage of the RQBI and an example to use the index. The purpose of this section is only to demonstrate a possible way to utilize the index, not to check its validity in practice, so some simplifications and assumptions are made. Due to the data availability, and many parameters in the RQBI are still need to be detected, only part of the construction is used as an example. The cost calculation is also simplified by using charging tariff from IM and only one category of freight wagons is discussed.

6.1 Implementation Proposal

An ideal platform to use the index is in form of a computer-based calculator. To put the index into practice, there are some main issues to solve. The first is the standardization of inputs. A computer-based practice could store characteristics of wagons and use them by selecting the wagon's name in an input page. The UIC classification is one option but it does not consider the impact of different bogies and it is coexist with other classification systems. In Sweden, further details of bogies and brake system could be obtained from the FORD system.

The second thing is detection of parameters. Possibly, some intermediate parameters' relation with input numbers may be detected in future, which means the parameters can be calculated and form as a part of the function. Some parameters can only be detected. Theoretically, those parameters should be detected by each single type of wagon. But this calls for a lot of work and cost. So a simplified method is to category the wagons, for example, by maximum axle load. Different sets of parameters would be selected when input wagons in different categories.

Third, some unknown parameters could be simplified to a default number. These parameters would not influence the comparative value of the indexes if set them as constants. For example, the locomotive tract the wagon and its related characteristics could set as default constants. The last step is to save these parameters in the database. The calculator can transfer relevant parameters according to the input data and then calculate the index of that wagon.

As mentioned before, a benchmark is proposed to set. Because it could be not fair to compare RQBIs among different UIC categories, benchmark of each category should be set separately. One initiation is to set the average index in the database of each category of wagons (e.g., flat wagon, covered wagon, tank wagon, etc.) as benchmarks. A benchmark index can then be calculated as,

$$(6.1) \quad \textit{Benchmark index} = \frac{RQBI(x)}{RQBI(\textit{benchmark})}$$

The benchmark index is large than 0. The average performance is 1 and a smaller benchmark index indicates a better performance. The benchmark would tend to be stable with the increment of input data.

In real practice, two different types of input method are recommended. In a simple input method, user only need to input type of topic wagon, usage per year, average speed, etc. And the calculator would transfer background data and default numbers from the database and use them together with the user’s input information to calculate both the RQBI and benchmark index. Another input method would be an extended input method. This input method would not require the user to provide all parameters needed in the index. This input would ask for a better description of the user’s wagon. For example, users may need to input some characteristics of the wagon themselves, and also the bogie’s information. Then the calculator would transfer less background parameters and default values comparing to simple input method to get a better evaluation of the target wagon. The procedure is shown in Figure 10.

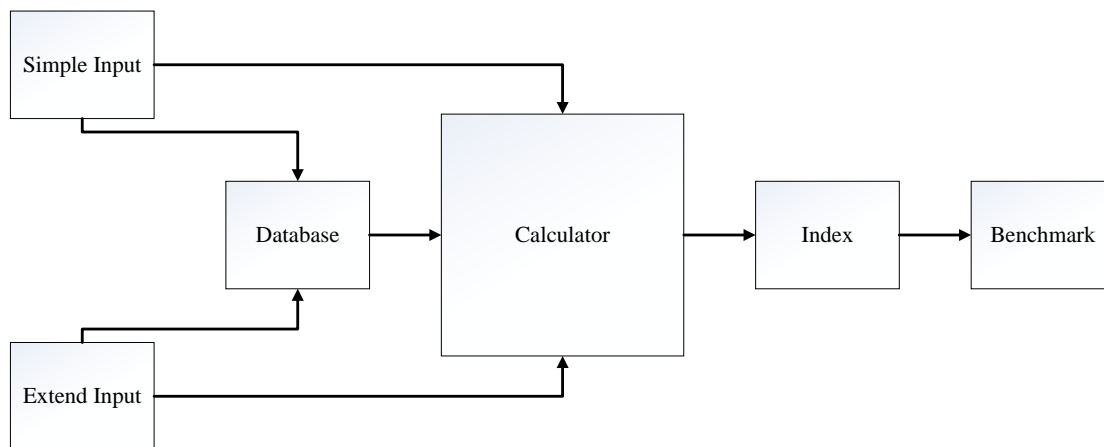


Figure 10. Implementation Procedures. Source: Authors

6.2 Calculation Example

6.2.1 Assumptions and Input Data

Only infrastructure cost is included in this section and the tariff from Trafikverket (2015) is used as a simplification. This simplification however would lower the efficiency of the index to reflect different wagons’ characteristics’ impact on the track.

Wagon’s information is from public page of one RU in Sweden (Greencargo, 2010). Only the S-category (special flat wagons with bogies) in UIC classification available on the public site is collected and compared. The real number of wagons in market could be reflected with the increment of inputs to the database. The database in the example is simplified 7 different types of S-category wagon and one wagon for each category.

In the calculation of the index, the wagons are compared in a same length period of time. The time span in the RQBI is set to be one year and for the convenience of calculation it is set to be one day (24h) in this example. Speed of each wagon is assumed to keep in the max speed. The speed of wagon would not influence the final index in this example.

The input data is listed in Table 9,

Table 9. Specifications of S-category wagons

Wagon types	Number of axles	Length (m)	Dead weight (kg)	Max axle load (kg)	Max loading weight (kg)	Max weight (kg)	Max speed (km/h)
Sdgms	4	18340	20500	20000	59500	80000	100
Sdggmrs (T2000)	6	34200	35000	22500	100000	135000	100
Sdggmrss (Twin)	6	34030	35000	20000	85000	120000	120
Sgns	4	19640	20000	22500	70000	90000	100
Sgnss	4	19640	20000	20000	60000	80000	120
Sgmmns	4	13600	17700	20000	62300	80000	100
Sgs	4	20640	22500	20000	57500	80000	100

Source: Greencargo (2010)

6.2.2 Calculation and Revision

The calculation result can be seen in Table 10.

Table 10. RQBI and Benchmark indexes of S-category wagons

Wagon types	Milage (km)	Charge (SEK)	RQBI	Benchmark Index
Sdgms	2400	1190.4	0.00257	0.961
Sdggmrs (T2000)	2400	2008.8	0.00286	1.071
Sdggmrss (Twin)	2880	2142.72	0.00350	1.311
Sgns	2400	1339.2	0.00224	0.837
Sgnss	2880	1428.48	0.00271	1.012
Sgmmns	2400	1190.4	0.00174	0.650
Sgs	2400	1190.4	0.00310	1.158

From the table, it can be seen that the Sgmmns wagon has the best performance, whilst the Sdggmrss has worst RQBI among all selected wagons. As mentioned before, it is noteworthy that the speed's influence cannot be reflected here. The RQBI of Sgns is better than the Sgnss's with all the specifications' keep the same except the operation max speed. The Sgnss's RQBI is worse because its loading capacity is lower with a higher speed.

The authors try to revise the input data by comparing them under a same speed. The revised input is listed in Table 11,

Table 11. Specifications of S-category wagons (Revised)

Wagon types	Number of axles	Length (m)	Dead weight (kg)	Max axle load (kg)	Max loading weight (kg)	Max weight (kg)	Speed (km/h)
Sdgms	4	18340	20500	20000	59500	80000	100
Sdggmrs (T2000)	6	34200	35000	22500	100000	135000	100
Sdggmrss (Twin)	6	34030	35000	22500	100000	135000	100
Sgns	4	19640	20000	22500	70000	90000	100
Sgnss	4	19640	20000	22500	70000	90000	100
Sgmmns	4	13600	17700	20000	62300	80000	100
Sgs	4	20640	22500	20000	57500	80000	100

Source: Greencargo (2010)

The calculation results after revision can be seen in Table 12.

Table 12. RQBI and Benchmark indexes of S-category wagons (Revised)

Wagon types	Milage (km)	Charge (SEK)	RQBI	Benchmark Index
Sdgms	2400	1190.4	0.00257	1.023
Sdggmrs (T2000)	2400	2008.8	0.00286	1.139
Sdggmrss (Twin)	2400	2008.8	0.00285	1.134
Sgns	2400	1339.2	0.00224	0.890
Sgnss	2400	1339.2	0.00224	0.890
Sgmmns	2400	1190.4	0.00174	0.692
Sgs	2400	1190.4	0.00310	1.232

When comparing under a same speed, the RQBI can better reflect the wagons' performances.

6.2.3 Application of a Bonus-malus System

In this section, the authors apply the RQBI and Benchmark index to a basic Bonus-malus System. The benchmark RQBI is set as a pivot point and wagons with RQBIs lower than 1 would get bonus whilst those with RQBIs bigger than 1 would get malus. The bigger the difference is, the more bonus/malus the wagon's RU would get. The bonus/malus could be calculated as,

$$(6.2) \quad \text{bonus/malus} = a(1 - \text{benchmark index})$$

a is a positive value which shall be decided by the authorities who give the bonus/malus. Wagon with better performance would have a benchmark index lower than 1 and get a number bigger than 0 from the equation as bonus and vice versa.

In practice, the a 's value need to be decided and further limits shall be applied to the equation.

7 DISCUSSION

This section discusses the features of the index and some limitation issues of the research.

7.1 Index Feature

Generally, the RQBI shown in equation (5.1) is cost-oriented. The reasons for this feature consist in three aspects. Initially, quality is a qualitative variable and the value of quality is hard to quantify directly. Then, when evaluating the quality performance, authors need to employ other quantitative variables to reflect the quality performance. Among these variables, cost is a metric variable that reflect the quality straightforward and easy to calculate. Secondly, compared to the charge from different authorities, cost can reflect the quality more directly. The amount of charge is normally base on actual cost with consideration on other aspects, e.g. policy orientation and market discrimination. Therefore, charge may not reflect the quality in certain cases. Thirdly, employing the cost variable to reflect the quality performance can be considered as an incentive for RUs to use more efficient wagons.

The RQBI still has the potential to better in the future. One consideration is to separate the RQBI into two parts. The IMs may more interested in costs on infrastructure and externalities and the RUs may more interested in costs on energy and maintenance. The way to compare the costs can also be discussed. In this research, the costs are compared within a same period of time and divided by the total mileage. This ignores the influence of the wagon's speed and real usage frequency.

7.2 Limitation

In this research, the issue of data availability is the main limitation. The authors cannot get access to all the data from RUs, Maintenance companies and Transport authorities through the interviews. Moreover, some measurement values cannot be detected directly as well. The deficiency of data poses an obstacle for the authors to verify the index validity and establish the real benchmark.

The reasons for the deficiency of data consist in two aspects. For one thing, our research topic is integrated with different aspects in rail transport region. Relevant organizations and individuals cannot be familiar with all of the aspects in the same time. Therefore, some values of the parameters included in the index may not be detected and gained before. For another thing, some data is not public and available to the outsider parties.

The RQBI has some limitations. The usage of the wagon's capacity is not discussed and the speed's different cannot be reflected in current construction. The construction still needs more calculation and revisions according to real situation.

8 CONCLUSION

In general, this research finished goals in the research proposal and tried to evaluate wagon's performance in different aspects.

RQ1: What kind of operation costs can be associated by the characteristics of wagons?

In operation costs, the infrastructure cost, energy cost and maintenance are determined or partly determined by wagon's characteristics. The infrastructure costs are charged by IMs according to wagon's characteristics and usages. The energy cost and maintenance costs are also associated with wagon's features and operations.

RQ2: What aspects shall be considered when evaluating wagon's performance?

In addition to aforementioned three costs, noise is one topic being focused in recent years. The cost of noise can also be calculated after detecting the wagon's noise level.

RQ3: What methods can be applied to detect relation between wagon's characteristics and final cost of each aspect? How to integrate them into an index to reflect the wagon's quality?

Methods to calculate different costs are collected and those bottom-up methods reflecting wagon's characteristics' influence on costs are more preferable. Different aspects of the wagon's quality are integrated in the form of cost. The total cost is compared among wagons within a time span of one year.

Admittedly, the index is not yet fully prepared to come into use, which is mainly due to the shortage of data. However, this research shed some light to the field of rail freight wagon's study. Other than take whole train into consideration, this research selected and concluded all quality aspects those could be influenced by the wagon's characteristics. With respect to the higher requirement on rail wagons in the future, this research pointed out a very interesting research perspective for further studies.

8.1 Future Research

The authors collected different costs related to rail wagons but there are still some limitations left to be solved in future research.

Firstly, the issue of data deficiency has been discussed in section 7.2, which is a main limitation in this research. In order to improve the data availability, the future research could strengthen the cooperation with relevant stakeholders. A deeper involvement can help researchers to easily get

access to the operation data.

Secondly, this research applied a life cycle cost method to calculate the maintenance cost each year. This is a more top-down method, which reflect little influence from the wagon's self-features. A bottom-up method, with the help of the FORD system recording wagons' maintenance information, could be possible to be derived and replace the current method using in RQBI.

Thirdly, further revisions of the RQBI are still needed. Due to the time limitation, the RQBI is not tested through practices. Though the authors intend to build an integrate tool to evaluate the overall performance of the wagon. Stakeholders in rail industry may have their each own emphasis. This fact gives the construction the potential to be used separately. For example, IMs may be more interested in the infrastructure cost from the wagons. Further researches could be focus on the specialized usage of the index in sub-industries.

References

- ANDERSSON, H. & ÖGREN, M. 2007. Noise charges in railway infrastructure: A pricing schedule based on the marginal cost principle. *Transport Policy*, 14, 204-213.
- ANDERSSON, H. & ÖGREN, M. 2013. Charging the polluters: A pricing model for road and railway noise. *Journal of Transport Economics and Policy (JTEP)*, 47, 313-333.
- ANDERSSON, M. 2011. Marginal cost of railway infrastructure wear and tear for freight and passenger trains in Sweden.
- BARKE, D. & CHIU, W. 2005. Structural health monitoring in the railway industry: a review. *Structural Health Monitoring*, 4, 81-93.
- BERGQVIST, R. 2015. Hinterland Logistics and Global Supply Chains. In: D-W, S. & P., P. (eds.) *Maritime Logistics: A Guide to Contemporary Shipping and Port Management*. London: Kogan Page.
- BERGQVIST, R. & ZUESONGDHAM, P. 2010. *Intermodal Freight Transport—Infrastructure and Technology*, BAS.
- BLADON, K., RENNISON, D., IZBINSKY, G., TRACY, R. & BLADON, T. 2004. Predictive condition monitoring of railway rolling stock.
- BLUMBERG, B., COOPER, D. R. & SCHINDLER, P. S. 2011. *Business research methods*, McGraw-Hill Higher Education.
- BOOYSEN, F. 2002. An overview and evaluation of composite indices of development. *Social Indicators Research*, 59, 115-151.
- BRAGHIN, F., LEWIS, R., DWYER-JOYCE, R. S. & BRUNI, S. 2006. A mathematical model to predict railway wheel profile evolution due to wear. *Wear*, 261, 1253-1264.
- BRENDEN, A. P. 2015.
- BROOMHEAD, S. F., HUNT, G. A. & THOMPSON, D. R. 1999. Usage Cost Model – v2. Derby: AEA Technology Rail report.
- BRYMAN, A. & BELL, E. 2011. *Business research methods 3e*, Oxford university press.
- BURSTOW, M. 2003. Whole Life Rail Model Application and Development for RSSB—Development of an RCF Damage Parameter. *AEA Technology Rail report AEATR-ES-2003-832 Issue*, 1.
- CALLONNEC, G. & SANNIÉ, I. Evaluation of the economic and ecological effects of the French ‘bonus malus’. In: BROUSSOUS, C. & JOVER, C., eds. *Act! Innovate! Deliver! Reducing energy demand sustainably*, 2009 La Colle sur Loup.
- CLEANSHIPPINGPROJECT 2013. Clean Shipping Index Guidance Document. Clean Shipping Project.
- COLLINSDICTIONARY. 2015. Collins Dictionary. Available: <http://www.collinsdictionary.com/> [Accessed 02-13 2015].
- COLLIS, J. & HUSSEY, R. 2013. *Business Research: A Practical Guide for Undergraduate and Postgraduate Students*, Palgrave Macmillan.
- CRESWELL, J. W. 2013. *Research design: Qualitative, quantitative, and mixed methods approaches*, Sage publications.
- DELFT, C. & INFRAS, F. I. 2011. External costs of transport in Europe. *Update Study for 2008*.
- DISTEFANO, A., FUSCO, G., GARGANI, F., LICCIARDELLO, R., LUPI, C., MASCELLARO, R., RICCI, S. & TIERI, A. 2007. Impact assessment study on rail noise abatement measures addressing the existing fleets.: PricewaterhouseCoopers.
- DJIA 2015. Dow Jones Industrial Average Fact Sheet. S&P Dow Jones Indices.
- EC 1998. White paper on fair pricing for transport infrastructure use. European Commission.
- EC 2002. Environmental noise directive 2002/49/EG. European Commission.
- EC 2011. White paper on transport. European Commission.

- EC 2014. EU transport in figures. European Commission.
- ECONOMICSHHELP. 2015. *Externalities – Definition* [Online].
Available: <http://www.economicshelp.org/blog/glossary/externalities/> [Accessed 04-17 2015].
- EKBERG, A. & PAULSSON, B. 2010. Concluding Technical Report. UIC.
- ERA 2014. COMMISSION REGULATION (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock – noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU. European Railway Agency.
- ESPOSITO, V. & NOCCHIA, S. 2008. Maintenance and repair of rolling stock*. *Welding International*, 22, 627-634.
- FLODEN, J. 2015.
- GERMAN, J. & MESZLER, D. 2010. Best Practices for Feebate Program Design and Implementation. ICCT.
- GREENCARGO. 2010. *Green Cargo Godsvagnar* [Online].
Available: <http://www.greencargo.com/vagnshandboken/sv/Godsvagnar/Start/Intermodala-vagnar/S-intermodala-vagnar/index.html> [Accessed 5-20 2015].
- HAIR, J. F., BLACK, W. C., BABIN, B. J. & ANDERSON, R. E. 2014. *Multivariate data analysis*, Pearson Education Limited.
- HÜBNER, P. 2008. Status report and background information on noise related track access charges. UIC.
- HÜBNER, P. 2009. Implementation of noise-related track access charges. Annex to "UIC Status report and background information on noise-related track access charges". UIC.
- ICCT 2011. The Energy Efficiency Design Index (EEDI) for New Ships. ICCT.
- ICMS. 2015. *Project: Container Port Productivity and Port Policy Evaluation* [Online].
Available: http://www.icms.polyu.edu.hk/research_portBenchmarking.html - [ReviewForTheIndustry](#) [Accessed 03-27 2015].
- INDEXMUNDI. 2012. *Rail lines (total route-km)* [Online].
Available: <http://www.indexmundi.com/facts/indicators/IS.RRS.TOTL.KM> [Accessed 02-28 2015].
- JOHANSSON, P. & NILSSON, J.-E. 2004. An economic analysis of track maintenance costs. *Transport Policy*, 11, 277-286.
- JONASSON, H. & NIELSEN, H. 1996. Road traffic noise-Nordic prediction method. *Nordic Council of Ministers, Tema Nord, Copenhagen, Denmark*, 1996525.
- JUN, H. & KIM, J. Life cycle cost modeling for railway vehicle. *Electrical Machines and Systems*, 2007. ICEMS. International Conference on, 2007. IEEE, 1989-1994.
- JURAN, J. M. & DE FEO, J. A. 2010. *Juran's quality handbook: the complete guide to performance excellence*, McGraw Hill.
- KCW, S. D. G., TU BERLIN 2009. Analyses of preconditions for the implementation and harmonization of noise-differentiated track access charges.: European Commission.
- MÄDLER, K. & BANNASCH, M. 2007. Materials used for wheels on rolling stock. *Deutsche Bahn AG, Technical Centre, Brandenburg-Kirchmöser, Germany*.
- MAGEL, E. E. 2011. Rolling contact fatigue: a comprehensive review.
- MANN, R. S., ABBAS, A., KOHL, H., ORTH, R. & GÖRMER, M. 2010. Global Survey on Business Improvement and Benchmarking. Global Benchmarking Network.
- MATSIKA, E., RICCI, S., MORTIMER, P., GEORGIEV, N. & O'NEILL, C. 2013. Rail vehicles, environment, safety and security. *Research in Transportation Economics*, 41, 43-58.
- MCGRANAHAN, D. V. 1972. Contents and measurement of socioeconomic development.
- MIEDEMA, H. & OUDSHOORN, C. 2001. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. *Environmental health perspectives*, 109, 409.

- MOYAR, G. & STONE, D. 1991. An analysis of the thermal contributions to railway wheel shelling. *Wear*, 144, 117-138.
- NATIONALMUSEUMWALES. 2008. *Richard Trevithick's steam locomotive* [Online]. Available: http://www.museumwales.ac.uk/rhagor/article/trevithic_loco/ [Accessed 02-28 2015].
- NBSC. 2015. *China Statistical Yearbook* [Online]. Available: <http://www.stats.gov.cn/tjsj/ndsj/2014/indexch.htm> [Accessed 02-27 2015].
- ODOLINSKI, K., NILSSON, J.-E. & WIKBERG, Å. 2014. The marginal cost of rail infrastructure maintenance; does more data make a difference? : VTI.
- OERTLI, J. & HÜBNER, P. 2010. Rail noise in Europe: A 2010 report in the state of the art. UIC.
- OKAMOTO, I. 1998. How Bogies Work. *Japan Railway & Transport Review*, 18, 10.
- ORR 1999. Railway Infrastructure Cost Causation.
- PALO, M. 2012. Condition monitoring of railway vehicles a study on wheel condition for heavy haul rolling stock.
- PALO, M. 2014. Condition-based maintenance for effective and efficient rolling stock capacity assurance A study on heavy haul transport in Sweden.
- PALO, M., LIN, J. & LARSSON-KRAIK, P. 2012. Maintenance performance improvement for rolling stock wheels.
- SANDBERG, U. & EJSMONT, J. A. 2002. *Tyre/road noise reference book*.
- SCHRAMM, G. 1963. Bogenwiderstand und Spurkranzreibung. *Eisenbahntechnische Rundschau, Darmstadt*, 12.
- TEIXEIRA, P. F. & PITA, A. L. 2012. UIC study on railway infrastructure charges in Europe. UIC.
- TELLISKIVI, T. & OLOFSSON, U. 2004. Wheel–rail wear simulation. *Wear*, 257, 1145-1153.
- THOMPSON, D. & JONES, C. 2000. A review of the modelling of wheel/rail noise generation. *Journal of sound and vibration*, 231, 519-536.
- TRAFIKVERKET 2015. Network Statement 2016. Trafikverket.
- TUNNA, J., JOY, R., SHU, X. & MADRILL, B. 2007. Methodology to Calculate Variable Usage Charges for Control Period 4.: TTCl.
- VOG, G., GACKENHOLZ, L. & WIEBELS, R. 1972. Die neue Formel (Hannoversche Formel) zur Bestimmung des Luftwiderstands spurgebundener Fahrzeuge. *ZEV-Glasers Annalen*, 96.
- VOLLMER, G. 1989. *Luftwiderstand von Güterwagen*, na.
- WENDE, D. 2003. *Fahrdynamik des Schienenverkehrs*, Springer-Verlag.
- WIKIPEDIA. 2015. Wikipedia. Available: <https://www.wikipedia.org/> [Accessed 03-16 2015].
- WORLDBANK. 2015. *Rail lines (total route-km)* [Online]. Available: <http://data.worldbank.org/indicator/IS.RRS.TOTL.KM> [Accessed 02-17 2015].

Appendix

Interview Guide

Interviewee	Organization	Purpose	Method
Anders Ekberg	Chalmers University of Technology	Data and methods to calculate infrastructure cost	Email
Anna Pernestål Brenden	Interfleet Group	Data availability in FORD system as input of this research	Email/Phone
Bo-Lennart Nelldal	Royal Institute of Technology	Data and methods to calculate maintenance fees	Email
Charlotte Högnelid	Trafikverket	Methods to decide infrastructure charges	Email
Jonas Floden	University of Gothenburg	Data and methods to calculate maintenance fees	Email
Pär-Erik Westin	Trafikverket	Methods to decide infrastructure charges	Email
Robert Bylander	Transportstyrelsen	Methods to evaluate and approve wagons	Email/Phone
Tomas Forsberg	SweMaint AB	Data and methods to calculate maintenance fees	Email/On site

Anders Ekberg (CTH).

By Email

Q1. What kind of factors may be applicable to a rail quality index on wagons? (With good data availability, probably parameters to transfer those factors into cost. Such as number of axles, average gross weight, speed, etc.)

Q2. Where can we get some data of such factors? Can we get some suggestions?

Anna Pernestål Brenden (Interfleet group).

By Email and phone

Q1. What information of rail wagons is included in the FORD system? In what form they are recorded?

Q2. Who are the main users of the system? Why do they use it? Who input the data to the system?

Q3. What kinds of vehicles are included in the system? Who are required to register in the system?

Bo-Lennart Nelldal (KTH) and Jonas Floden (GU).

By Email

Q1. About the work, "Enhetskostnader för godstransporter med järnväg - Underlagsrapport till projektet Strategisk modellering mellan landsväg och järnväg", has been cited as reference from many other researchers' articles. We wonder whether it could be convenient to ask for a PDF version from you?

Q2. About the organization called “SIKA” (Swedish Institute for Transport and Communication Analysis), we found many articles used publications from this organization as references. However, it seems like they are out of business? Otherwise are there any alternatives we could turn to for some data?

Charlotte Högnelid, Pär-Erik Westin (Trafikverket).

By Email

Q1. We would like to ask in which aspects would Trafikverket evaluate the performance of the wagons? For example, maybe environment, maintenance or energy consumption?

Q2. How would Trafikverket set charges to different types of wagons? What is the rationale behind that?

Robert Bylander (Transportstyrelsen)

By Email

Q1. In which aspects would Transportstyrelsen evaluate (or set standard to) the performance of the wagons? For example, maybe environment, maintenance or energy consumption?

Q2. Does your department have any preference on those well-performed wagons? What are the differences between them and those "bad" ones?

Q3. If we would like to benchmark the performance of wagon, what do you think can be set as a benchmark in this industry, which kind of freight wagon has the best (or ideal) performance in today's industry?

By Phone

Q1. How rail vehicles are approved by your department? (Any processes? Do you need to inspect them? Or just some paperwork from manufacturers? Re-checks?) Do you have any available document or data of the approvals?

Q2. Is bogie the most decisive part of a vehicle's performance (capacity, maintenance, etc.)?

Q3. Are most vehicles "bogied" in Sweden or in Europe? Does it mean the bogie is same to "running gear"?

Q4. Is a latter type of vehicle means better performance? In which aspects they are improving?

Tomas Forsberg (SweMaint AB)

By Email

Q1. Normally, in the maintenance industry, how does people further category the maintenance of rolling stocks? For example, maybe categories by the parts like bogies, wheels, and pantograph?

Q2. How would SweMaint set charges to different kinds of services? What is the rationale behind that?

On site

Q1. Would you please brief us some basic information on freight wagons, bogies, wheel sets?

Q2. What are SweMaint's main services? What is the procedure of these services? Do you have maintenance services on locomotives?

Q3. How do you set your charges? Shall we ask for some exact information on these?

Q4. Does relevant authorities has requirements on wagon's maintenance?

Q5. What kind of wagon's characteristics would influence its maintenance cycle? Does modern wagons mean less maintenance cost?