CCRDMT
COMPETENCE CENTER FOR THE ASSESSMENT OF RAILWAY DIAGNOSTIC AND MONITORING TECHNOLOGIES

Railway Safety Research – A Cross-Disciplinary Literature Review

Prof. Dr. Harald F.O. von Korflesch
Mathias Linden
André Schneider

WORKING PAPER 17-002

IFET

UNIVERSITÄT KOBLENZ · LANDAU

RAILWAY SAFETY RESEARCH – A CROSS DISCIPLINARY LITERATURE REVIEW

Arbeitsberichte des Competence Center for the Assessment of Railway Diagnostic and Monitoring Technologies (CCRDMT) - CCRDMT Working Paper Series 17 Volume 2

ISSN 2700-6506

Kontaktdaten der Verfasser

André Schneider
Mathias Linden
Prof. Dr. Harald F.O. von Korflesch

CCRDMT
am Zentralen Institut für Scientific Entrepreneurship & International Transfer (ZIFET)
Universität Koblenz-Landau
Universitätsstraße 1
D-56070 Koblenz
E-Mail: ccrdmt@uni-koblenz.de

Juni 2017

Abstract

Railway safety is a topic which gains the public attention only if major railway accidents happen. This is because railway is considered as a safe mode of travel by the public. However, to ensure the safety of the railway system railway companies as well as universities conduct a broad spectrum of research. An overview of this research has not yet been provided in the scholarly literature. Therefore, this thesis follows two objectives. First an overview and ranking of railway safety research universities should be provided. Second, based on these universities, it should be identified which are the most relevant and influential research topics. The ranking is based on the research method "literature review" which forms the methodical basis for this thesis. To evaluate the universities based on a measurable and objective criterion, the number of citations of the researchers from each university is gathered. As a result, the University of Leuven for the civil engineering, Milan Politechnico for mechanical engineering and the University of Loughborough for electrical engineering are identified as the leading university in their field of railway safety research. The top universities for each discipline are distributed all over Europe, North America and Asia. However, a clear focus on the US and British universities is observed.

For identification of the most relevant and influential topics the keywords from the publications which are considered in the ranking procedure are analyzed. Focus areas among these keywords are revealed by calculating the count of each keyword. High-speed trains as well as maintenance are recognized as the highly relevant topics in both civil and mechanical engineering. Furthermore, the topic of railway dynamics for mechanical engineering and noise and vibration for civil engineering are identified as the leading topics in the respective discipline.

Achieving both research goals required exploratory approaches. Therefore, this thesis leaves open space for future research to deepen the individual topics which are approached in each section. A validation of the results through experts interviews as well as a deepening of the analysis through increasing the number of analyzed universities as well as applying statistical methods is recommended.

Eisenbahnsicherheit ist ein Thema, welches in der Öffentlichkeit weitestgehend nicht beachtet wird, solange kein schwerer Eisenbahnunfall passiert. Dieser Umstand ist damit verbunden, dass die Eisenbahn als sicheres Verkehrsmittel wahrgenommen wird. Jedoch forschen sowohl Eisenbahnverkehrsunternehmen als auch Universitäten in diesem Bereich, um zu gewährleisten, dass der hohe Sicherheitsstandard erhalten werden kann. Eine Übersicht über die Forschung, die in diesem Bereich betrieben wird, ist in der gängigen wissenschaftlichen Literatur nicht verfügbar. Deshalb werden in dieser Abschlussarbeit zwei Ziele angestrebt. Zuerst soll eine Übersicht und eine Rangliste für die Universitäten, die Forschung im Eisenbahnsicherheitsbereich betreiben erstellt werden. Anschließend wird basierend darauf eine Identifikation der wichtigsten und einflussreichsten Themen durchgeführt. Die Rangliste wird auf Basis der Forschungsmethode „Literature Review" angefertigt. Um die Universitäten und Forscher in eine sinnvolle und objektive Rangliste zu bringen, muss ein Kriterium festgelegt, welches diese Bedingungen erfüllt. Dafür wird die Anzahl an Zitationen, die die Publikationen der einzelnen Wissenschaftler erhalten haben, herangezogen. Als Resultat daraus sind die Universität Leuven für das Fach Bauingenieurwesen, die Polytechnische Universität Mailand für das Fach Maschinenbau und die Universität Loughborough für das Fach Elektrotechnik als führende Einrichtungen identifiziert worden. Die besten Universitäten in den einzelnen Disziplinen stammen aus Europa, Nordamerika und Asien. Jedoch kann ein Schwerpunkt in den USA und in Großbritannien festgestellt werden.

Zur Identifikation der wichtigsten und einflussreichsten Forschungsthemen werden die Schlagwörter, die den Publikationen der einzelnen Wissenschaftlern zugeordnet sind, analysiert. Um Schwerpunkte zu erkennen, wird die Häufigkeit der Schlagwörter ausgewertet. Hochgeschwindigkeitszüge und Wartung konnten als übergeordnet wichtige Themen in den beiden Disziplinen Maschinenbau und Bauingenieurwesen identifiziert werden. Zusätzlich wurden die Themen Eisenbahndynamik für Maschinenbau und Vibrationen und Lärm für Bauingenieurwesen als führend erkannt.

Um die beiden Forschungsziele zu erreichen, mussten explorative Methoden angewendet werden. Daher lässt diese Abschlussarbeit Raum für viele weitere Forschungsvorhaben, welche auf den Ergebnissen dieser aufbauen. Eine Validierung der Ergebnisse durch Experteninterviews sowie eine tiefere Analyse durch Erhöhung der Anzahl der einbezogenen Universitäten oder die Anwendung von statistischen Methoden ist daher empfehlenswert.

Aus Gründen der besseren Lesbarkeit wird auf die gleichzeitige Verwendung männlicher und weiblicher Sprachformen verzichtet. Sämtliche Personenbezeichnungen gelten gleichwohl für beiderlei Geschlecht.

Table of Contents

1 Introduction 1
1.1 Motivation and Problem Statement 2
1.2 Research Objectives 6
1.3 Methodical Approach 8
1.4 Structure 9
2 Theoretical Foundation – Literature Review and Railway Safety 10
2.1 Railway Safety as a Selection Criterion 10
2.2 Literature Review – An Overview 13
2.2.1 Definition 14
2.2.2 Types 15
2.2.3 Purposes and Rationale 20
2.2.4 Methodology 23
2.2.5 Literature Search 26
2.2.6 Selection Criteria 29
2.2.7 Tools 30
2.2.8 Recommendations 31
2.2.9 Cautions 32
2.3 Implications of this Chapter for the Thesis 33
3 Identification and Categorization of Researchers and Universities 35
3.1 Description of Identification Process 35
3.1.1 Aggregation of Information from Different Sources Part 1 35
3.1.1.1 Eisenbahnlehre.org 37
3.1.1.2 Railway Technical Research Institute 38
3.1.1.3 Railway Research UK Association 38
3.1.1.4 International Railway Research Board 38
3.1.1.5 National University Rail Center 39
3.1.1.6 Railway Talents 39
3.1.1.7 Cooperative Research Centers Australia 39
3.1.2 Aggregation of Information from Different Sources Part 2 40
3.1.3 Selecting the Researchers 41
3.2 Categorization and Ranking of Researchers 52
3.2.1 Categorization Method and Distribution Analysis between Categories 52
3.2.2 Development of the Ranking Procedure 56
3.2.3 The Top Five Civil Engineering Universities 63

3.2.4 The Top Five Mechanical Engineering Universities.....65
3.2.5 The Top Three Electrical Engineering Universities.....69
3.2.6 Overall Implications from the Ranking in the Three Categories 71
4 Publication Analysis for the Identification of Relevant Research Topics 74
4.1 Method for Identifying the Most Relevant Research Topics 74
4.2 Application of the Method on the Selected Publications 77
4.2.1 Observations during the Agglomeration Process 77
4.2.2 Keyword Analysis for Civil Engineering.....78
4.2.3 Keyword Analysis for Mechanical Engineering 81
5 Conclusion and Outlook.....85
5.1 Conclusion.....85
5.2 Outlook.....90
6 Bibliography.....93
7 Appendix.....96

Table of Figures

Figure 1: Fatalities for different transport modes per billion passenger kilometers in the EU (2010-2014) (Own diagram following European Union Agency for Railways 2016) 4

Figure 2: Railway fatality risk and passenger fatality risk for EU-28, USA, Canada, South Korea and Australia (2010-2014) (Own diagram following European Union Agency for Railways 2016) 5

Figure 3: Research Steps (Own Diagram) 8

Figure 4: The Safety and Security Umbrella (Own diagram following Coursen 2010). 11

Figure 5: Flowchart of the Identification Process (Own Diagram) 36

Figure 6: Distribution of Disciplines between Selected Universities (Own Diagram) .. 53

Figure 7: Distribution of Countries between Selected Universities (Own Diagram)..... 55

Figure 8: Five Overall Most Cited Civil Engineering Universities (Own Diagram) 63

Figure 9: Top Five Civil Engineering Universities Based on Average Citations (Own Diagram) 64

Figure 10: Five Overall Most Cited Mechanical Engineering Universities (Own Diagram) 66

Figure 11: Top Five Mechanical Engineering Universities Based on Average Citations (Own Diagram) 68

Figure 12: Three Overall Most Cited Electrical Engineering Universities (Own Diagram) 70

Figure 13: Top Three Electrical Engineering Universities Based on Average Citations (Own Diagram) 71

Figure 14: Most Mentioned Keywords for Civil Engineering Word Cloud (Own Diagram) 80

Figure 15: Most Mentioned Keywords for Mechanical Engineering Word Cloud (Own Diagram) 83

List of Tables

Table 1: Overview of the Four Types of Literature Review Proposed by Huff (Own table following Huff 2008)..... 17

Table 2: Comparison of Different Categorization Models (Own Table) 20

Table 3: Categorization of Purposes for Reviewing Literature (Own Table) 22

Table 4: Comparison of Literature Review Methodologies (Own Table) 25

Table 5: Identified Universities According to Selection Criteria (Own Table) 44

Table 6:Ranking and Categorization of Selected Universities (Own Table) 57

Table 7: Most Mentioned Keywords for Civil Engineering (Own Table) 78

Table 8: Most Mentioned Keywords for Mechanical Engineering (Own Table)..... 81

List of Abbreviations

CCRDMT……...Competence Center for the Assessment of Railway Diagnostic and Monitoring Technologies

ERA .....European Railway Agency

GRADE ..... Global Railway Accident Database and Evaluation

THE ..... Times Higher Education

UIC .....Union internationale des chemins de fer

1 Introduction

The CCRDMT is a competence center at the Central Institute for Scientific Entrepreneurship and International Transfer (ZIFET) at the University of Koblenz-Landau. At this institute transfer between universities and industrial partners should be facilitated. By forming a competence center like the CCRDMT with a regional industry partner in 2014, the knowledge transfer between industry and research is supported. The research of the CCRDMT focuses on the usage of information and communication technologies (ICT) in the railway sector. It specifically investigates diagnostic and monitoring technologies, which use ICT to communicate relevant data to the railway undertaking. Overall the CCRDMT supports the three strategic objectives of railway operators: increasing safety, improving efficiency and increasing availability. Therefore, the research is relevant for all stakeholders in the railway sector. Since the research is located at the interface between information technology (IT) and business management, this interdisciplinary research focus offers great flexibility in identifying as well as intensifying new research fields.

Currently, the CCRDMT follows three research projects. First the advancement of the Global Railway Accident Database and Evaluation (GRADE), which enables economic analysis as well as evaluation of railway accidents based on more than 43,000 railway accidents from 18 countries is a major goal. Second, interviews with infrastructure managers from European countries are conducted to identify their usage as well as alarm processes regarding wayside monitoring systems. Third, basic research in predictive maintenance and usage of Big Data in the railway sector, which is one of the most emerging topics on the market, is one of the future research topics for the CCRDMT.

This thesis is embedded into the research of the CCRDMT. How the research conducted for thesis supports the objectives of the CCRDMT is described in the following chapter. At first the motivation and problem statement, on which this thesis is build up on, are described in detail. The leading questions for this section are on the one hand: “Why is railway safety still an important topic?” and on the other hand: “What are the benefits of identifying important researchers in the railway safety area?”. Second, the four research objectives and research questions are mentioned and explained in detail. Third, the methodical approach is explained by introducing the methods used for fulfilling each research step. Last, the structure of the whole thesis is described to provide an overview of the following chapters.

1.1 Motivation and Problem Statement

As the CCRDMT is a small research institution, it is essential to find partners for cooperation and collaboration to fully exploit the research capabilities in respective research fields. However, it is difficult to find and engage with new partners. From an industry's perspective, academic research plays a tangential role in their daily business and recognizing the long-term benefits of such a partnership requires a broader vision. Therefore, establishing industry partnerships is a long term task which can be troublesome. Gaining industry partners is one of the possibilities for collaboration. However, it seems more promising to win new partners in the academic field since these partners should follow the same interests. Currently, the CCRDMT has not established any strong relationships to other academic researchers, mainly because of its novelty as well as its lack of focus on this endeavor. Therefore, the overall goal of this thesis is not only to identify but also to analyze new potential academic research partners for the CCRDMT as well as to provide a review of the current state of research in different fields of the railway sector.

To perform this analysis several preconditions, have to be defined to determine the scope of this thesis. At first the set of topics and research fields included in this analysis have to be defined. Since most of the topics covered by the CCRDMT are related to increasing railway safety, this field of research forms the guideline for selecting if research fields are or are not included in the analysis. Therefore, the main question leading the selection process is: "Does this research influence railway safety in any possible way?". If this question can be answered in the positive, the research field and the respective researcher are included. This topic selection especially refers to the goal of the GRADE project which should help railway companies in justifying their railway safety investments. In this database 283 accident causes are defined which cover every area potential defect in the railway system[1]. Therefore, safety improvements could also originate from several fields of research (such as computer science, civil engineering or mechanical engineering). To better understand frequent areas of failure, it would be important for the CCRDMT to identify experts in the respective area. Furthermore, the long-term benefit of this identification could be the establishment of networks as well as the exploitation of synergies between the different research fields. There are several positive examples from

[1] For further information on the GRADE database see: www.grade-railway.com

the United States, Australia or Great Britain, which show that cooperation between different universities can be very fruitful[2]. Establishing such a network in Germany or forming a cross national platform is both a challenge as well as an opportunity for the future and is already started by UIC with platforms like Railway Talent[3] or the International Railway Research Board (IRRB). However, these networks are either too small to be significant or have a very specific focus like fostering education of railway engineers worldwide. Therefore, there are several opportunities for using the research in this thesis as an impetus for establishing a railway research network.

To develop this identification of universities and researchers as well as review and analysis process upon a scientific method a literature review is used to determine the most influential articles in the respective research fields. The chosen process is explained in more detail in section 1.3. From a scientific perspective, a literature review is the best method to classify the influence of a researcher on his field since the quality of the work can be defined by the number of citations. Additionally, it is also possible to find out which topics are currently of the highest interest in the scientific community by considering the year of publication and how the thematic focus changed in the recent years. This information will help to define research areas which reflect current trends in the railway sector and should also be considered by the CCRDMT for adapting its research focus.

In the bigger picture, it is important to understand why railway research is still an important topic today. From an average consumer's perspective, the assumption could arise that railway safety research is no longer of high importance since the public perception is that railway accidents are a rarity in the developed countries. An assumption which is shared by the scientific community as well (Edwards 1997). However, this statement is only partly true. In the 28 states of the European Union the number of accident victims reduced from 1,270 in 2010 to 963 in 2015 (Eurostat 2017). The constant decrease shows that safety improvements in the railway sector are already making an impact. Still this number means that almost 1,000 people per year lose their lives in railway accidents. From the ERA's perspective, who is responsible for the improvement of railway safety this number forms a challenge for their future work. Their goal is to ensure that every member state reaches the European Union average of 0,28 fatalities per million train kilometers (European Union Agency for Railways 2016). These numbers combined with the

[2] For a further elaboration on the benefits of these organizations see: section 3.1

[3] For further information on the RailwayTalent Program by UIC see: www.railwaytalent.org

goal of the subordinate railway institutions like the era show that railway safety is a topic worth investigating.

The topic of safety is especially important since the railway operators are in direct competition with other transport modes and therefore, besides profitability, the safety is one of the key selling points to their customers. As illustrated in Figure 1, in relative comparison to frequently used means of travel railway is the second safest mode of transportation. However, when it comes to long distance travels, railway stays in competition with the airplane, which can offer cheaper prizes and shorter travel times. Therefore, it is important, that railway increases its level of safety while decreasing costs to offer cheaper prices for its customers. This competition between safety and cost-efficiency is a phenomenon which can be observed in many other industries (Farrington-Darby et al. 2005)

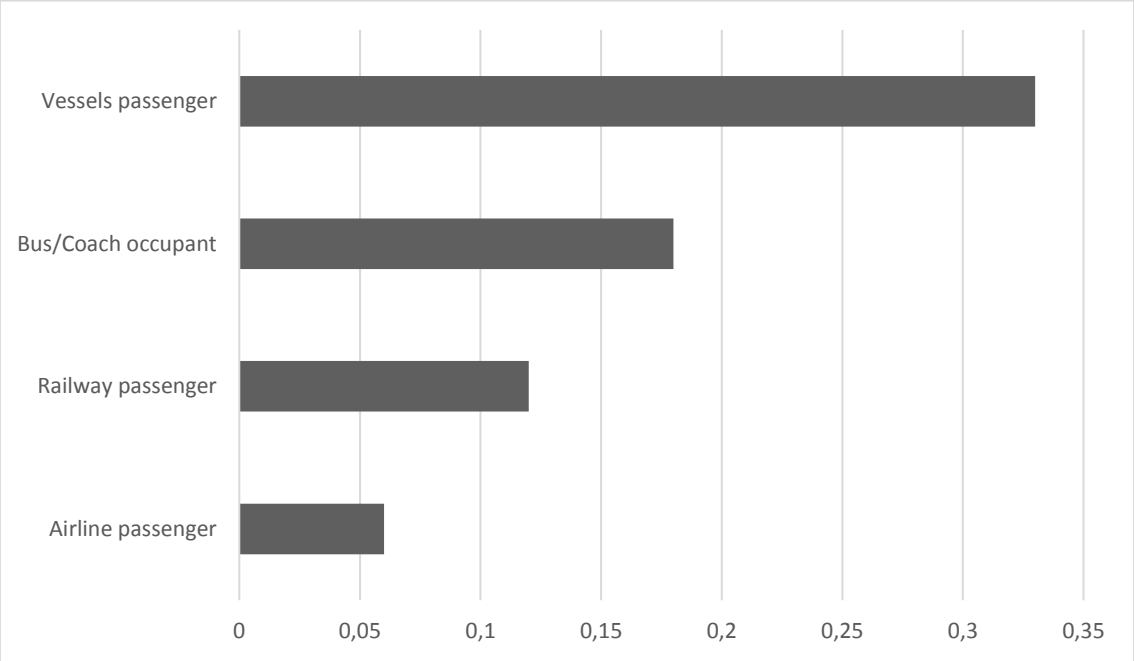

Figure 1: Fatalities for different transport modes per billion passenger kilometers in the EU (2010-2014) (Own diagram following European Union Agency for Railways 2016)

Furthermore, the scholarly exchange as well as identifying the excellent researchers in each research field regarding railway safety can be very beneficial for increasing railway safety all over the world. As presented in Figure 2, there are still major differences regarding the safety level of railway on the different continents.

In Japan, for example, there was no passenger fatality in the respective years. This can be explained by their smaller railway network as well as their passenger orientation. However, this cannot be the only reason why they outperform European countries in that area

to such an extent. Further reasons as well as studies regarding that issue can be found in academic literature[4]. Additionally, this thesis could be the starting point for identifying potential research cooperation between Asia and Europe to better understand the benefits of both railway systems.

The first and most important argument for researching as well as improving railway safety is the opportunity to save human lives by preventing accidents or mitigating the effects of a potential accident. However, as already outlined in the previous paragraphs, the economic influences of railway accidents for the railway operators should not be underestimated.

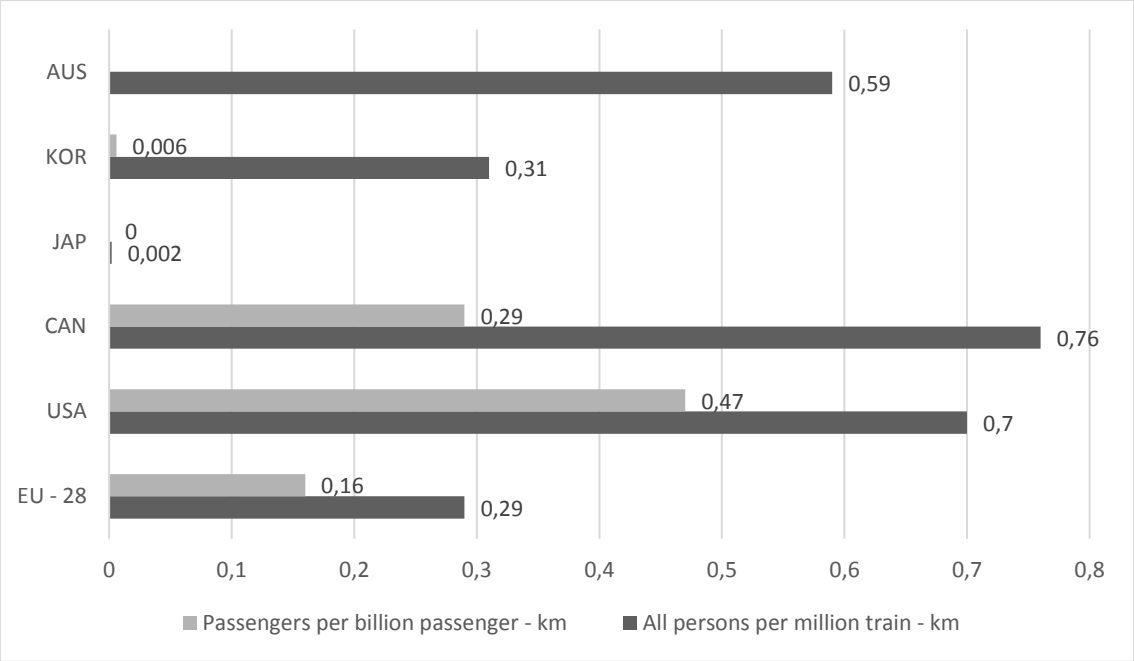

Figure 2: Railway fatality risk and passenger fatality risk for EU-28, USA, Canada, South Korea and Australia (2010-2014) (Own diagram following European Union Agency for Railways 2016)

The railway accident database GRADE serves as an appropriate example for this argument. In this database accident data from 43,000 accidents out of 18 countries is aggregated. From an economic perspective, the costs, which are caused by an accident, are most important. Germany servers as a good example since 70 major accidents occurred here between 2000 and 2014. These accidents caused total damages of 375 million Euros[5]. However, these are only the major accidents. All minor accidents, which did not exceed the reporting limit, are not included into the database. This means that the actual

[4] For a better understanding of railway safety in Japan see: Arai (2003)

[5] See: www.grade-rail.com

amount would be several times higher. Since the importance of saving costs to stay competitive compared to other modes of transport is already outlined in previous paragraphs, it is obvious that improving railway safety goes hand in hand with increasing cost efficiency. The idea behind as well as the scientific foundation for developing GRADE is provided in a conference paper by Linden et al. (2015).

1.2 Research Objectives

The overall goals of this thesis are to identify the most influential researchers in the railway research field and in combination to this objective to determine which topics are currently most significant in railway research. Therefore, a literature review over different sub-disciplines of railway research is conducted to achieve these overall goals.

To give a better overview the overall goals are divided into four main objectives, which are worked on sequentially. The objectives are used as the basis for developing the research questions which follow in this section.

The first research objective is to identify the most influential researchers and respective universities in the field of railway safety. There are several soft criteria like the number and size of cooperation with industrial partners, membership in important networks, speeches at industry events or scientific conferences. However, these criteria are all difficult to measure as well as hard to evaluate. Therefore, the number of citations as well as the quality of the publications assessed based on the publications ranking are the most objective criteria. The advantage of this identification is that an overview and structuring of the railway safety research topic is provided. However, this is only the one of the benefits of reaching for this objective. In a broader perspective, cross-national networks between research, industry, government and other stakeholders could be established, which would advance the whole industry. Furthermore, collaboration between researchers from different research fields could be established based on this objective. Especially the potential identification of unknown interfaces between the research work from different disciplines can be beneficial for both sides.

The second objective of this thesis is the identification of the most relevant and current topics in the railway safety research field. The motivation for this objective is based on several arguments. On the one hand, it is necessary for the whole research community to identify which topics are in the current research focus and which topics will probably gain attention in the upcoming years. This information is important since it defines how researchers should change, broaden or intensify their research in the future. On the other

hand, a research-practitioner gap, which could be existent in a specific research field, can be detected. As railway safety research is an applied science whose results should be adopted by related stakeholders, it is important to evaluate if the current research topics reflect the practitioner's actual problems. Therefore, the identification of these topics can lead to an advance in closing the academic-practitioner gap.

The third objective of this thesis is to define a categorization scheme for the different areas in railway safety research. As already outlined in the previous section, railway safety research originates from different scientific disciplines. Since it would be highly complex as well as unrewarding to compare researchers from different disciplines, a categorization scheme is necessary which clearly separates the different research areas dealing for example with one specific aspect of railway safety. The problem of a cross-disciplinary comparison would be that a comparison on the basic publications is impossible since the types, number and ranking of different publication types vary strongly between different disciplines. Therefore, the aim is to identify which research areas topics can be aggregated in a single research area which is clearly separable from others. This is a highly complex task since there is a lot of research at the interface between different disciplines in a field like railway research which origins from mechanical engineering but especially evolved through technological development to a highly diverse research field.

The fourth objective is the development of a methodology which enables to determine the relevance of a topic in railway safety research. The implementation of this objective is based on the previously conducted literature research. Since classical approaches like a series of interviews with experts as well as practitioners are too extensive for this research project a more agile approach based on the literature research is developed. The benefit of this approach is that it does not require any additional data collection. Not conducting any expert interview is a clear limitation for reaching the objective because the gathered data will lack of validation. However, developing a new approach could be a starting point for future endeavors in other disciplines. As a follow-up to this work the quality of the methodology could be evaluated by conducting interviews with professionals from the relevant research areas. This questionnaire could collect the data for comparing the identified topics with the valued opinion of experts.

Each research objective is used for the development of the research questions (RQ) which will be used as guideline throughout the research:

RQ1: Who are the most influential researchers and universities in their respective area of railway safety research?

RQ2: What are the most relevant topics in railway safety research?

RQ3: How can railway safety research be categorized?

RQ4: How can relevant topics in railway safety research be identified?

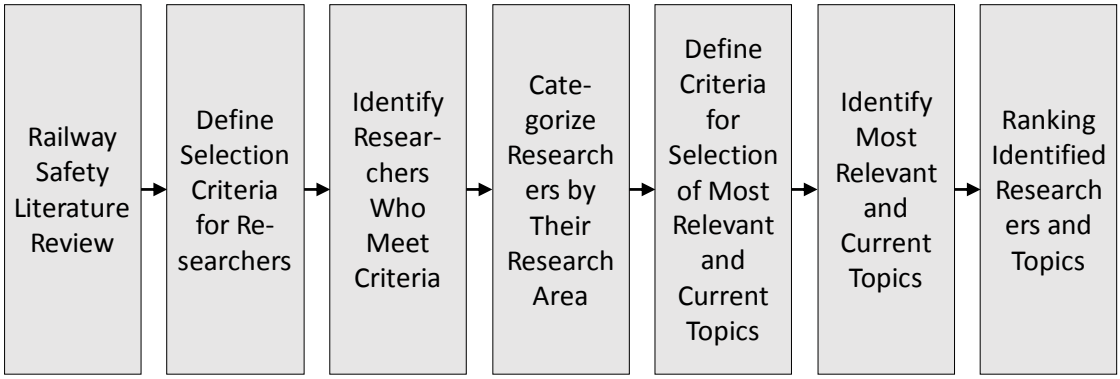

Figure 3: Research Steps (Own Diagram)

The research objectives as well as the research questions are reflected in the research steps (see Figure 3), which must be undertaken sequentially to achieve the single objectives. The explanation of how each of these steps is conducted methodically is described in the following.

1.3 Methodical Approach

This thesis is divided into several steps which are displayed in Figure 3. Each of these steps is based on a methodical approach which is explained in this chapter. The methods used for conducting this research are a mixture of classical approaches like literature analysis and more modern approaches like tagging or keyword analysis.

In a first step a literature review on the topic of literature analysis in different disciplines is conducted. This helps to develop a basic understanding of how important and influential literature can be identified. Additionally, the term railway safety is defined and explained to gain an understanding which sub disciplines are part of railway safety research. Following this task a desk research is conducted to identify universities which perform research in railway safety. In this thesis railway safety is defined broadly since every sub discipline of railway research contributes to increasing railway safety in different ways. Therefore, those universities are identified which deal with safety-related topics of railway research. Afterwards these researchers are selected based on criteria like number of

citations, international orientation, quality of publications or language of publication. Thereby, a framework is developed which defines how many of the criteria have to be fulfilled to be included in the analysis. After having identified of the researchers their publications are used to classify the topics. Additionally, these publications have to be selected according to previously defined criteria. Hence, criteria like number of citations, publication date, language or publication type are used to evaluate the quality of a publication.

After this selection process a newly developed method for identifying the most relevant and current topics is proposed. It is based on the keywords as well as individual tags by the author of this thesis if no keywords exist. Since the keywords briefly describe the most important content of a publication, they should be a good indicator of the topics covered in the respective publication. Afterwards the identified keywords are statistically analyzed and ranked to identify the focus of each railway safety research field.

1.4 Structure

The following section describes the structure of the overall thesis which is aligned to the research step in Figure 3. In Chapter 2 the results of the literature research on the topic of literature analysis and review are described in detail. This theoretical foundation should serve as a basis for the further research work in the following chapters. In Chapter 3 the identification and categorization process of relevant researchers is at first described and then this process is applied and the results as well as the identified researchers and their universities are introduced. Chapter 4 begins with a detailed description of the process used for the publication analysis. Thereafter the results of the analysis are displayed and described. The list of the most relevant and current topics is subsequently used as a basis for evaluation as well as developing research implications for the future. In Chapter 5 the implications of this thesis for the CCRDMT as well as the whole research community are outlined. The thesis is rounded up by a conclusion and outlook which describes further opportunities for research based on the results of this thesis.

2 Theoretical Foundation – Literature Review and Railway Safety

This chapter is divided into two parts. At first the topics of railway safety and how it is perceived in this thesis is explained in detail to provide a basic understanding of the criteria used for selecting the relevant researchers and publications in Chapters 3 and 4. After that the process of reviewing literature is introduced based on broad spectrum of literature sources dealing with topics research design, literature review and research methods. Rounding up this chapter is a short section on the implications of the theoretical part for the following Chapters 3 and 4, in which the literature review is applied. These implications should form a basis for adapting the review process to the requirements of this thesis.

2.1 Railway Safety as a Selection Criterion

To decide which researchers are integrated in the review in Chapter 3 and 4, selection criteria have to be developed to provide a clear data basis for the analysis and evaluation in these chapters. One of the criteria is the topic's relation to railway safety which includes the challenge of covering its very broad spectrum. As the GRADE database shows, more than 280 different causes could be identified for the included railway accidents. All these causes somehow relate to a research topic in the scientific community. Since the GRADE database is broad-based, the literature review will align to that and not only focus for example on causes induced by failures of train components.

Before introducing the selection, process based on several examples the term safety is defined especially in distinction to security. In German language, there is no linguistic difference between safety and security since both terms are translated with the word "Sicherheit". Therefore, it is even more important to differentiate the meanings of both words in the English language. There are several blog articles on the web explaining the differences between safety and security since it is for example a major differentiation in IT security. For undergraduate students understanding this differentiation can be difficult. However, it is essential to allocate respective measures to the threats harming the security or safety of a IT system. According to Maeve Maddox (2010) safety is the "state of being safe, the exemption from hurt or injury, the freedom of danger". On the other hand, she defines security as "the condition of being protected from or not exposed to danger". When taking a closer look at the origins of both words, one can find safety originating from the Latin "salvus", which means uninjured or healthy. While security derives from "securus", which means "without care" (Maddox 2010). Transferring that to a more practical explanation, one could say that security is the protection of external factors like being

robbed. Therefore, security cameras are installed and not safety cameras. Safety, on the other hand, is more complex. It is a feeling that the environment one is a part of at that specific moment is safe (for example knowing that the car has been in maintenance regularly). Although both definitions try to circumscribe safety from security, this is not entirely possible since one influences the other. An appropriate metaphor is Spencer Coursen's umbrella, as displayed in Figure 4 (Coursen 2010). This illustration shows that security somehow spans safety, which is also easily understandable through the following example. Looking again at cars, the airbag is a security and a safety feature depending on the kind of threat the driver has to face. When another car crashes into the own car in an accident, which is not caused by the own car, the airbag is a security feature which protects the driver from the consequences of the accident (external failure). When one, for example, loses the control over his car in a corner and crash into a tree, the airbag is a safety feature which protects one from his own failure (internal failure). This short example depicts the close connection of safety and security and shows how security measures will also improve safety.

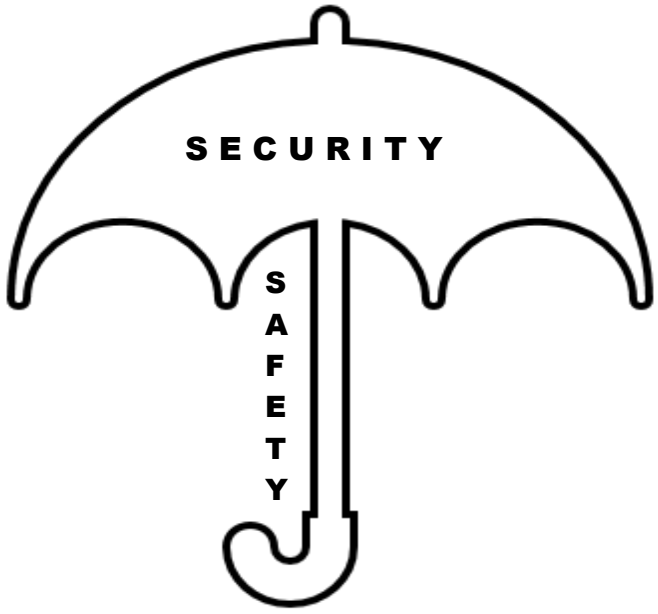

Figure 4: The Safety and Security Umbrella (Own diagram following Coursen 2010)

The car example is an appropriate explanation for the connection between safety and security. However, the effort to increase a system's security can also contradict the goal of ensuring safety for example when looking at at fire escapes in buildings: On the one hand they increase the residents' safety, on the other hand they create an additional access

points for thieves (Springer n.d.). These two short examples show, that safety and security can go in support as well as contradict each other. Therefore, evaluating different measures should be done with care if they can be allocated to safety or security and how they influence both constructs. Especially the example of IT security demonstrated above shows that a clear distinction between both constructs does no longer apply in real industry systems (Springer n.d.). Industry 4.0 is a buzzword nowadays, railway cannot withstand the changes caused by this development. Trains as well as their components are equipped with sensors which are connected via networks. This development requires elaborate security measures since attacks on the information technology could possibly harm the overall systems' safety. Based on this example one can see that nowadays external attackers can influence parts of systems or machines which beforehand would only be harmed from an internal position. Therefore, the borders between safety and security start to blur in most industries.

In this research project railway safety is examined. Since IT security is relevant for railway safety but the research on IT security is not directly railway related, the topic will not be covered in the analysis. This is mainly because IT security is a broad topic in which advancements are achieved on a more generic level which does not interfere with railway research. In the upcoming paragraph, further selection criteria for researchers are explained, which will be applied in Chapter 3.

The first rule for selecting the relevant researchers is basic: If the research covers a topic which will improve the railway's safety in general, the researchers is included. So, for example, a researcher who is working on improvements in the durability of the track bed does not have the focus on improving railway safety. However, in the long run, higher durability means run less accidents caused by failures of the track bed. Therefore, these researchers would be included in the analysis. On the other hand, a researcher, who is for example analyzing how to improve timetables of railway lines or a whole railway network, aims to increase the efficiency of railway traffic. However, he does not improve railway safety, not even in a broader sense. While in most cases this selection criteria work out well, there are some cases in which it is difficult to decide if there is a relation to the railway safety topic. For example, some researchers deal with the topic of improving training of train drivers. This is a possible measure for increasing railway safety. However, it is very difficult to allocate the effects of training to potential safety improvements. Furthermore, the CCRDMT has a rather technical or technologic view on railway safety originating from the research interests of its members. The origin of the researchers

focusing on the improvement of train driver training is related to psychology and education. These are both topics in which the CCRDMT is lacking expertise to make significant contributions to research, which is why the researchers are not included in the analysis

2.2 Literature Review – An Overview

This section forms the theoretical part of this thesis by introducing the literature review as a research concept. To better understand why reviewing literature is not only method but also a necessary skill every researcher need to acquire at the beginning of his scientific career, one should consider the quote of Webster and Watson (2002: 8):

"A review of prior, relevant literature is an essential feature of any academic project. An effective review creates a firm foundation for advancing knowledge. It facilitates theory development, closes areas where a plethora of research exists, and uncovers areas where research is needed."

This quote shows the relevance of the literature review as a starting point for every academic project. The area of railway safety is the focus of the CCRDMT's research objective. Therefore, understanding the current progress in other scientific disciplines also dealing with the same general topic is elementary for finding new research opportunities as well as identifying theories and concepts used in this research area.

Guiding through this chapter are the questions a novice researcher would ask himself when conducting a literature review for the first time:

1) What is a literature review?
2) Why should a researcher conduct a literature review?
3) How is a literature review conducted?

For answering these questions this section starts with defining the term literature review. Afterwards the different types of literature reviews identified by various scholars are described and compared. This is followed by an explanation of the several purposes of literature which are closely linked to the reasons why a literature review is conducted. For conducting a review, it is necessary to understand which steps one should follow. Therefore, different methodologies introduced by well-known scholars are compared. As an important part of the review process, the literature search is examined more closely to find a solid basis for the searching process in this thesis. Additionally, selection criteria for supporting the decision on which sources should be included in the review as well as helpful tools which can support the whole process are discussed as well as introduced. To

provide the reviewer with some helpful feedback on applying the methodology helpful recommendations, which can be crucial for simplifying the process, are introduced as well. Rounding up this section a short elaboration on the cautions one has to consider is conducted.

2.2.1 Definition

According to Cooper (1998) literature review is a term which is congeneric with several other terms and used for the same endeavor. These congeneric terms like for example literature analysis can sometimes be used synonymously with the term literature review. Based on the research conducted for developing literature review is identified as the most commonly used term by scholars. However, one has to be when interchanging these terms since their meaning can differ in its rigor (Cooper 1998). Guides for literature review come along with a comprehensive methodology which consists of several steps, some of these steps are elaborate procedures which can be used as stand-alone method, as well. Therefore, the reason for confusion between the different terms is obvious. Also, keeping in mind that scholars differ between different types of reviews (see Section 2.2.2), it is necessary to provide a general definition what a literature review is and how it is implemented as a research methodology. A comprehensive definition is provided by Hart (1998: 13), which will serve as guideline in this thesis to convey a common understanding of the term[6]:

"The selection of available documents (both published and unpublished) on the topic, which contain information, ideas, data, evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed."

This definition can be split into three parts. At first the documents on the investigated topics have to be selected. This selection process requires an in-depth literature search beforehand (see 2.2.5). The process is guided by goals of the research supported by this literature review. Afterwards these documents are analyzed and evaluated to find a solid basis for the related research. Based on this definition one can easily recognize that achieving a useful result requires systematic approach. Some authors differentiate between systematic and unsystematic approaches. However, Booth (Booth et al. 2012) state

[6] For a further collection of definitions see: Ridley (2012)

that this assumption is misleading since any kind of empirical work requires a system by its nature. Therefore, the comprehensiveness and the complexity of this task make an unsystematic approach obsolete. The comprehensiveness as well as the degree of detail for a literature review depend on both the chosen methodology (see 2.2.4) as well as the type of literature review (see 2.2.2). The necessity of a clear methodological approach is often underestimated but ultimately forms the basis for an effective literature review (Levy & Ellis 2006). This is one of the characteristics which Levy and Ellis (2006) point out as a key success factor. Additionally, they point out that researchers should keep in mind, that firm basis, which a literature review provides, serves as a baseline to demonstrate the new contribution of the proposed research endeavor (Levy & Ellis 2006).

This foundation provided by the literature review should be used to position the own research among the other sources in the own research area (Ridley 2012). However, this statement is only applicable to research conducted in an area which is already examined to a degree in which a broad foundation is existent. In some areas, which have not yet been in focus of scholarly activity, a literature review is not the means of choice for starting a research project. So, exploratory research as it is performed in this thesis cannot be based on a conventional literature review as proposed by several guidebooks. Still the differentiation of Ridley (2012) is applicable which divides the term literature review into two parts: The product which is the results of performing according to the above-mentioned methodology and will be the starting point for the research. The second and equally important part looks at the literature review from a process perspective which is performed gradually throughout the research project. Each step a researcher has to follow to complete his endeavor should be guided by literature supporting as well as justifying the current action. In conclusion, it can be stated that a literature review is neither a single nor simple task. Conducting a full literature review requires a wide range of activities to achieve satisfactory results for the whole research project.

2.2.2 Types

In the previous section, different types of literature reviews are already partly introduced. To provide a more comprehensive understanding of the differentiation between different types of literature review, this section elaborates on this topic in more detail. Before beginning to introduce these different types, a problem in differentiating between them is identified. There is no exact definition of type, which leads to a problem when comparing the different concepts scholars use to differentiate. Therefore, in this section three different approaches are introduced chronologically, which were proposed by different authors.

Cooper (1998) recognizes two different types of reviews. His concept is cited by several scholars like Torraco (2005) later on. However, it also the least complex differentiation of the three introduced in here.

Cooper's first type is called integrative literature review or research synthesis (1998). The integrative literature review investigates empirical studies as well as other previous work of scholars which examined the same or any related hypothesis to show the current state of knowledge as well as gaps in research (Cooper 1998). This integrative review provides the firm foundation required for any research endeavor. The second type identified is the theoretical literature review. In differentiation to the integrative review the theoretical review looks closer at several kinds of theories explaining the same phenomenon or hypothesis with the goal of assessing which theory is the most powerful or best fitting (Cooper 1998). The only further explanation by Cooper is that the integrative can vary in its comprehensiveness by including more variables as well as related hypothesis (Cooper 1998). Webster and Watson (2002) as well as Torraco (2005) pick up the Cooper´s concept of the integrative review and extend it by including the maturity of the topic as another variable.

A more elaborate approach to divide literature review concepts into different types was conducted by Huff (2008). She aligns her differentiation not on the focus of the literature review but how the way of conducting a literature review changes throughout a research project. In the beginning a literature survey is performed to define the subject domain of the research project (Huff 2008). In this case the literature survey serves as an inspiration as well as a valuable input for a future research project. The focus of the next proposed stage of literature review, called critical review, is more narrow than just surveying (Huff 2008). In comparison to the survey the researcher now examines specific articles or books which could serve as a basis for starting the project, which is currently in development (Huff 2008). Still the researcher needs to be susceptible for inspiration from other researchers or external sources. The third type identified by Huff (2008) is the systematic review which should be applied on the next stage of research, when the research questions have already been defined. Based on this question the researcher looks for related work which can be valuable for his own project (Huff 2008). The analysis and following synthesis of this sources forms the ideal basis for practical research or concept development (Huff 2008). The fourth type of literature review is the supportive one. The supportive literature builds up on the concept of the literature review as a process, which is already introduced in 2.2.1. As a research project evolves the researcher needs to reevaluate his

project after he finishes an important step of work. Performing this reevaluation process, it has to be considered that the overall framework the research is placed in can no longer be changed (Huff 2008). For a better understanding the following table provides an overview of the different types introduced by Huff (2008).

Table 1: Overview of the Four Types of Literature Review Proposed by Huff (Own table following Huff 2008)

	Survey	Critical Review	Systematic Review	Supportive Research
Purpose	• Identifying the interesting research areas • Finding key issues and trends	• Identifying relevant authors • Finding common standards • Identifying areas for contribution	Capturing the results of current investigation in the intended field of contribution	Using literature to underpin your arguments as well as to solve specific problems
Primary Sources	• Sources from previous research • Conversation with other researchers • Journals and books in the research field	Articles and other forms of publications from well-known scholars in my subject area	Multidisciplinary bibliographic databases	Limited to journals in the investigated research field
Rules	• Routinely monitor the literature in the respective discipline	• Define an initial question and perform a literature analysis on this question to reevaluate	• Define an overarching research question • Identify scholar's	Think outside the box and search for related sources which were not

	• Include all kinds of information sources	your question • Critical evaluation of arguments in the identified sources	contribution to the same question • Obtain expert feedback	identified during the original survey
Electronic Tools	• Bibliographic software • Specialized mapping software • Online Conversations	• Web of Science • Specialized mapping software • Database software	• Multiple search engines • Tools for statistical analysis • Programs for collecting and analyzing qualitative data	Specialized databases
Information desired	• Identification of interesting subjects for new scholarly projects • Annotated references • Mind map and/or concept map of the research domain	• Key concepts and arguments in the respective research field • Identification of research gaps or other lacks in argumentation	• Edited results of related quantitative research • Evidence tables for summarizing qualitative research	Relevant connections to other literature sources, which are not already included in the analysis

Criteria for closure	No closure as long as the field is of interest, however as the research project evolves, the effort should be decreased	Reaching a solid basis for a new contribution	Confidence that the new project will contribute something new to the research field	Confidence that current and past literature is considered that other researchers can follow the argumentation

While Cooper differentiates the various types of literature research according to their focus and Huff bases her differentiation on the evolvement of the project, the third kind of conducting this task is introduced by Okoli & Schabram (2010), who use the type of the underlying research project as criterion for differentiation. According to their work three types of literature review exist. The first is the theoretical background which forms the theoretical foundation as well as the context for the research questions of a journal article (Okoli & Schabram 2010). This type of review has primarily two purposes. At first it should found the basis for the main study following in the article (Okoli & Schabram 2010). Additionally it should capture the current state of research regarding the respective research question (Okoli & Schabram 2010). The second type is the literature review for a graduate thesis. The comprehensiveness depends if this thesis is performed by an undergraduate, graduate or doctoral student. However, all these kinds of thesis share the same goal by showing the supervisor that the student has a comprehensive knowledge and understanding of his research field. In a doctoral thesis it is specifically required that the review justifies the novelty of the research endeavor (Okoli & Schabram 2010). The third category is the stand-alone literature review which is the most elaborate of the three. In this type an article of journal-length is proposed without obtaining any new data or proposing a new study (Okoli & Schabram 2010). The reviewer wants to achieve overall understanding of the research field as well as identifying gaps or new sources which have not yet been recognized by other authors (Okoli & Schabram 2010). In differentiation to the two other types the scope of the review is much broader and the requirements for rigor are much higher which makes it a systematic review. This is already used as a category by Huff (2008). The only constraint a potential reviewer has to consider is that the systematic review is only applicable to elaborate and develop research topics since a firm basis of literature is required to perform it (Okoli & Schabram 2010).

In the following table the different approaches for categorizing literature reviews are summarized. Each of the categorization is applicable, it depends on the reader's focus which categorization fits his needs best. However, Huff's categorization is the most practice-oriented since the different categories are assigned to the progress of a potential research project. This differentiation can be very helpful especially for novice researchers.

Table 2: Comparison of Different Categorization Models (Own Table)

	Cooper	Huff	Okoli & Schabram
Types	• Integrative literature review • Theoretical literature review	• Survey • Critical review • Systematic review • Supportive research	• Theoretical background • Thesis literature review • Stand-alone literature review
Distinguishing criterion	Focus	Progress	Project

2.2.3 Purposes and Rationale

The reasons for undertaking a literature review are manifold. Several scholars designate a variety of reasons for conducting a literature review. Additionally, most of them outline its high importance to any research project. To handle the variety of reasons in this section a categorization as well as condensation of the most frequently mentioned reasons is conducted. For this categorization the arguments of eight different publications are used: Cooper (1998); Creswell (2013); Hart (1998); Marshall & Rossman (2014); Okoli & Schabram (2010); Levy & Ellis (2006); Ridley (2012); Booth et al. (2012). At first every purpose statement of these authors is examined in detail to identify superior categories. Thus, five main categories (related purpose statements between at least three different authors) and five minor categories are identified.

The first main category of purpose statements for literature research is called "foundation and context". The generalized purpose statement would be that the literature research on the one hand forms a foundation for the following research project by providing the reader with the work of other well-known scholars in the research field. On the other hand, the

research for which the literature review provides the basis needs to be placed in the context of other work, so the reader can understand on whose research this new project builds up on.

The second main category is closely linked to the first one and is called "issues and methodologies". While the purpose of "foundation and context" is more generally focused on the overall research conducted in the respective research field, in the "issues and methodologies" category the purpose outlined by the authors is more detailed. Understanding central issues, problems and challenges in the research field is one of the main goals of conducting a literature review since these issues can be used as a baseline for justifying the new research project. Furthermore, providing an overview of the methodologies, concepts and theories used by other scholars in the same research field is key for choosing the best fitting methodology for the own project.

The third main category is also closely linked to the first one since it is dealing with the identification of "research gaps". This task is not only very important for identifying a new research project but it is additionally also based on first developing an understanding of the research field as well as getting familiar with the work of other scholars. If one has acquired a thorough knowledge of his preferred research field, he will also be able to see where there is a lack of research. However, it has to be kept in mind that it is not the gap on its own which can justify the research. The researcher still has to argue that the contribution of his research is valuable and advancing the progress in the respective research field.

The fourth main category is kind of the opposite of the previous one since it is about the identification of "bridges between topics". Again, a close relation to the first category is existent since an in-depth foundation and knowledge on the topic is required before one can identify these bridges. In this case, it is not about identifying relations between topics which are already described by other scholars. The results achieved by reaching for this purpose are dependent and open a scholar's the perspective. If one is not only covering the well-known literature in a research field but also looking at related disciplines and their publications, new insights could be achieved for example into methodologies frequently used in two different disciplines. Because of this, new linkages, which a scholar would not think of in the first place, could be identified.

The fifth and last main category of purposes for conducting a literature review is called "justifying the research project". For every research project, there is a need to somehow

motivate as well as justify to the mentor, the scientific community or the industry partner why this research is conducted. Therefore, the research problem as well as the resulting research questions and objectives have to be outlined and set in the context of the overall research on the respective topic. The establishment of the research questions as well as the research goals is ideally a process which is initiated by conducting the literature review, since getting familiar with other scholars' research, will always throw up questions which could be the starting point for a new endeavor.

Table 3: Categorization of Purposes for Reviewing Literature (Own Table)

	foundation and context	**issues and methodologies**	**research gaps**	**bridges between topics**	**justifying the research project**	
Booth	X	X	X	X		4
Cooper	X	X		X		3
Creswell	X		X			2
Hart	X	X	X	X	X	5
Levy & Ellis	X		X		X	3
Marshall & Rossman	X		X		X	3
Okoli & Shabram	X					1
Ridley	X	X	X			3
	8	4	6	3	3	**24**

To provide an overview of which purpose is mentioned by which researcher and to better understand the process of selecting, these five main categories of purposes are illustrated in Table 3 and sorted according to the mention of which category by which author.

Based on this contingency table the relevance of the categories as well as the authors can be analyzed and evaluated. The most frequently mentioned purpose is building a foundation as well as placing the research in the context of the research field. The reason for that is obvious since all kinds of scholars, but especially novice researchers, have to gain an in-depth understanding of their research field before being able to start any kind of research project. The research gaps category is also leading with six mentions in total which demonstrates the fact that these gaps are one of the most used as well as most established reasons for starting a research project. Following the frequency of mentions per authors is analyzed. Booth and Hart with mentioning the purposes of five respective four of the main categories lead this statistic. Both have conducted an in-depth guide book for scholars and students to perform a comprehensive and elaborate literature review. Therefore, their elaboration on providing the rationale for a literature review is the most comprehensive. The other authors like Creswell have written books on broader topics in which literature review is only a chapter or journal articles such as Levy & Ellis. For both types of publications, the limited number of pages is the reason for a less detailed elaboration.

Additionally, five minor categories are identified which are not as frequently mentioned by well-known scholars in comparison to the main categories. These minor categories of purposes are: criticizing the work of others, lining out the significance of a topic, building links between practice and theory, gaining a new perspective and learning the subject's vocabulary. These minor categories are also related to the major categories. However, they will not be discussed in detail in this thesis because of lacking significance.

2.2.4 Methodology

In this section methodologies for reviewing literature proposed by several others are compared and analyzed to obtain suggestions for the literature review performed later. Since literature reviewing is a highly comprehensive as well as important task, a structure for conducting the review is an essential requirement for it. Without following a clear methodology with separated and elaborated research steps, one could quickly get lost during this elementary phase of starting a research project.

In this section three methodologies are regarded. One of them is taken over from Cooper's "Synthesizing Research: A Guide for Literature Reviews". The other two are obtained from Creswell (2013) and Okoli (2010). Cooper is chosen because it is one of the first books on the topic and therefore it is used as a foundation for their work from many other scholars who are writing books or articles on how to conduct a literature review. Creswell

is selected because his book is one of the most cited and most relevant research design books in the academic world. Additionally, Okoli & Shabram are included since their work was combining several methodologies from other well-known authors to create a new and improved version. Okoli & Shabram use articles and books by other highly relevant authors in the field like Kitchenham (2004) or Petticrew & Roberts (2008). Therefore, these three methodologies form a broad basis for comparison.

Before comparing theses three methodologies each of them is shortly described to provide the reader with a basic understanding of the work of each of these scholars. Cooper (1998) proposes a five-step methodology describing each step in detail in a separate chapter of his book. The methodology is described in this paragraph according to Cooper's book. As an initial step, the researcher needs to decide which problem to investigated. Therefore, he has to choose which type of studies should be included in the review to narrow the research field down. Hence, criteria for distinguishing between relevant and irrelevant studies should be formulated. In the following step, the data has to be collected via literature search based on the criteria developed in the first stage. Afterwards the collected data is evaluated by its quality to decide which sources are going to be discarded. Furthermore, the sources which have proven relevant are analyzed and interpreted to identify the main concepts, methodologies and theories. Finally, these results are presented in a written report or any other kind of documentation.

The methodology developed by Creswell (2013) consists of seven steps instead of five and is therefore more detailed than Cooper's. Creswell starts with identifying keywords which are necessary to obtain the relevant material in the next steps. Next the literature search follows using every potentially available source from web databases to classical library information systems. If this search is finished, the scope of the literature integrated in the review has to be narrowed down. Creswell recommends 50 articles or books which have to be evaluated in the next step to identify the most relevant for the chosen topic. Out of these relevant sources Creswell suggests conducting a literature map to group the main topic into categories. After its completion, the most relevant articles have to be summarized and thus form a basis for the last step which is the creation of the final document.

Okoli & Shabram's methodology (2010) consists of eight steps. The first step starts with the formulation of the purpose of the chosen literature to justify the endeavor. Afterwards they recommend training the reviewers to achieve familiarity with the common standards

for the respective project. Then the reviewer can start the literature search process. Following the results of this search are examined to decide which studies are included in the analysis later. Based on this examination criteria have to be outlined to justify why articles are included or discarded in the review process. If the relevant articles are selected, the data which is required for the research project can be extracted. Finally, this data has to be synthesized to combine the work, concepts, results of different authors to achieve one common written report.

Table 4: Comparison of Literature Review Methodologies (Own Table)

Cooper	Creswell	Okoli & Shabram	Aggregation
Problem Formulation	Identify Keywords	Purpose of the Literature Review	Preparation
		Protocol and Training	
Literature Search	Literature Search	Searching the Literature	Search
Data Evaluation	Location of Relevant Articles and Books	Practical Screen	Evaluation
Data Analysis	Identify Central Articles or Chapters	Quality Appraisal	Analysis
		Data Extraction	
Interpretation and Presentation	Design a Literature Map	Synthesis of Studies	Synthesis
	Summarize the Most Relevant Articles		
	Assemble and Structure the Review	Writing the Review	Finalization

In Table 4 the three different methodologies are compared and condensed to an aggregated more general approach to perform a literature review. Examining the three methodologies six basic steps could be identified. At first the review has to be prepared for example by identifying the relevant keywords. Okoli & Shabram (2010) require two steps for this because they assume that multiple researchers are contributing to the project. The following step is searching for literature which is defined by all three authors. After that the results of this search have to be evaluated to decide which publications are included. This is the same for each of the authors, however they use different vocabulary. Following the included articles are analyzed to identify the central and relevant parts of them. This step is also part of all three introduced methodologies. Contrasting the others, Okoli & Shabram divide this analysis into two steps, which is structural and not a substantial difference. The synthesis and finalization step however vary between the three authors. While Cooper performs synthesis and finalization as one step, the other two authors split it up. Whereas Creswell uses the literature map as a tool to structure the identified work and to reveal relations, Okoli & Shabram recommend synthesizing the results from the previous step in any form the reviewer prefers. As a final step, each of the authors recommends presenting the results in any form of written publication.

Concluding it can be stated that there are no substantial differences between the methodologies of the three introduced authors. Concerning the content, they all use similar approaches to perform a literature review. Since conducting a literature review is a highly-structured process and different well-known authors build up on the previous relevant work of others, this should be rather clear. However, there is still a difference of focus on the single steps, which is due to the authors having different origins concerning their disciplines and the methodologies being introduced at different times. Changes for example through digitalization also have to be regarded in the methodologies since the Internet completely changed the way of searching for literature. This explains the varying emphases of the three authors.

2.2.5 Literature Search

This section deals with one of the most important stages of literature review and an endeavor which is difficult to master for novice researchers. Before starting the review process, a researcher has to be clear on which keywords he wants to use for searching, since missing a highly relevant keyword for the respective topic could harm the whole review process. Additionally, when identifying the relevant sources two major questions for each researcher come up: first, are all relevant sources identified, second, when can the search

process be stopped. These two questions are opposed to each other since the fear of missing a highly relevant source could lead to an endless search process. Therefore, criteria have to be identified which define when to stop the search process.

Before starting the discussion on these issues a definition for literature search is provided to ensure a common ground for this section. Gash (2000: 1) defines literature searching as:

> *"A systematic and thorough search of all types of published literature in order to identify as many items as possible that are relevant to a particular topic"*

From this definition one can also recognize the difficulty which is already outlined beforehand that it is only possible to identify as many items as possible. This means, there is no insurance for missing important evidence. Therefore it is important to continue the search process at later stages in the review process (Ridley 2012). Today this task is easy attended since there is more and better software as well as Internet databases available than ever before (Ridley 2012). However, these capabilities also come at a prize of getting lost in an overload of information. Several authors provide frameworks which describe the steps of literature searching in detail[7]. Especially novice researchers should follow these frameworks to ensure not getting lost in information.

Defining the right keywords is an important starting point for the literature search process. However, it can be difficult for researchers, who are new to a field, to decide for the right keywords (Levy & Ellis 2006). If this is the case researchers should use a classification scheme which is provided by publishers or research organizations (Levy & Ellis 2006). They divide the research field into relevant subfields. Levy and Ellis (2006) additionally provide two cautions to be considered when defining the keyword list. First, keyword search can and should not be the only method for identifying relevant sources since this method will not lead to identifying all relevant publications. This is especially true for research fields with relation to any kind of modern technology. In those areas terms change so quickly that after ten years a previously prominent keyword can become outdated. Second, a researcher has to consider trends when assembling his keyword list. Again, especially in quickly changing research field terms can be in the center for interest for a short period and then disappear from the surface completely.

[7] Since describing these frameworks would exceed the scope of this section, the interested reader should follow Ridley (2012) or Booth et al. (2012).

After identifying these keywords, they have to be applied to search engine to obtain the relevant publications. Since major journals are recommended to begin with by several authors for identifying the most important articles, databases provided by the most relevant publishers like JSTOR or ScienceDirect/Elsevier can be a good starting point. However, if one decides to start more comprehensive literature review, search engines like Google Scholar or the Web of Knowledge are the best beginning. Especially Google Scholar lists the contributions of all major journals and is therefore also the starting point for the search in this thesis (see Chapter 3). It is not only through convenience and familiarity with the Google search engine, that Google Scholar is selected. One of its major benefits is that it is not focused on a specific discipline. This renders it more convenient for the cross-disciplinary review conducted in this thesis. Furthermore it is also recommend by several well-known authors like Booth et al. (2012), Creswell (2013) and Okoli & Schabram (2010).

As already outlined beforehand if the keyword list is well defined and the search engine/database is selected, applying the keywords to the respective source will usually lead to comprehensive results. However, one has to be careful to not fall for the deception that the literature search is completed after finishing this stage. The keyword search will seldom cover the whole research field. Therefore, it is necessary to use additional methods to identify other relevant sources which have fallen through the net of keyword searching. Booth (2012) and Levy & Ellis (2006) recommend two ways of doing so. One is the snowball method which means using a highly relevant article as a basis and searching its reference list to understand the foundation of this research, which is a way of considering the past and thereby neglecting more recent publications. On the other hand, through modern databases like the Web of Knowledge there is also a way of considering the future. By using the way of identifying articles which cite a relevant article of the research field, one can gain a better understanding how a research field evolved. This paragraph shows that keyword searching as an identification method without additional validation.

There are more methods which are in some cases more useful than the ones already outlined. In some disciplines the quality and relevance of a publication highly relates with the reputation of a journal (Webster & Watson 2002). Therefore, skimming these journals could be a fruitful approach for getting an overview of the respective research field (Booth et al. 2012). Additionally, another way of doing so is looking for publications of specific authors which are major contributors to a research field. A good example would be Creswell who is also cited in this thesis. His book on research design is cited over 60,000

times according to Google Scholar. So, if a researcher is examining this topic, he should look through all publications by him. This author centric approach is also used in this thesis since the primary motivation is to identify relevant researchers.

2.2.6 Selection Criteria

After having identified the relevant literature, the researcher has to decide how to choose the articles which are of relevance to the specific review. This is a very important step because it prevents the reviewer from getting lost in an overload of publication and it forces him to define criteria which can be used to guide this selection process (Okoli & Schabram 2010). Therefore, in this section some applicable selection criteria are presented.

First the publication type should be an indicator of the quality as well as the relevance of a publication. This argument is picked up by several authors and is also used in the review conducted in this thesis. The priority list of which sources should be selected first is provided in the following table. This table presents rankings by Creswell and hart, two different but both highly relevant authors in the field of literature reviewing.

Creswell	Hart
1) Literature reviews and encyclopedia articles 2) Journal articles 3) Books 4) Conference papers 5) Dissertations 6) The Web	1) Published books 2) Journal articles 3) Theses and conference papers

Comparing these two rankings one can recognize the inversed ranking of journal articles and books between the two authors. This is a decision for which each of the authors provides his individual reasons. However, it depends on the discipline which sources should be preferred. Both authors agree on the ranking of dissertations and conference papers. The only difference is that Creswell also recommends the Web as least valued source and provides the suggestion to start with other already conducted literature reviews and overview articles before starting the identification process of specific publications.

A second criterion which should be considered is the number of citations a publication has. The frequency of citation is both an indicator of relevance and shows whose work is the most influential for the respective research field (Hart 1998). The citation frequency

also enables the researcher to conduct a relevance tree which shows the relation between key articles and how theories or methodologies are disseminated (Hart 1998).

There are several other criteria which have to be considered during the selection process. The date of publication can be very important depending on the discipline which is reviewed (Okoli & Schabram 2010; Huff 2008; Jourdan et al. 2008). In some disciplines like philosophy the relevance of the sources could not be related to the date (Huff 2008). However, in a technology dependent discipline like railway safety research publications can quickly become outdated. Therefore a fixed timeframe should be set to decide which articles are to be selected (Okoli & Schabram 2010). Looking through the literature in chronological order also bears the advantage that one can recognize trends as well as developments of concepts throughout a period.

For the selection of relevance the title as well as the author of the publication can be an indicator (Okoli & Schabram 2010; Jourdan et al. 2008). The title already decides if the publication fits the topic of interest. Additionally, the author is a quality criterion, since the biography as well as the university can show the author's reputation in the scientific community. Furthermore, the language of the publication has to be considered as well. Publication in the native language of an author, which are not translated to English, are an indicator of minor relevance (Okoli & Schabram 2010). After considering all the selection criteria stated in this section especially novice scholars should rely on the feedback of experienced researchers in the field to ask them for support or for missing important publications (Booth et al. 2012). This section on the selection criteria shows that it is important to not only identify the relevant literature but also to evaluate it based on objective criteria to ensure a high quality of the publications.

2.2.7 Tools

This section introduces tools, which can be helpful for conducting a literature review. The word "tools" does not limit to IT related tools, it basically includes all kind of helpful methods for facilitating the conduction of the review process.

One idea is provided by Creswell (2013) who introduces the concept of the literature map as a tool for structuring the selected publications. As an example he provides the literature map conducted by Janovec (2001), which is an instance for novice researcher who are unsure how to structure their sources. A literature map is a graphical representation of the relation between the most relevant publications. Therefore, the research topic is grouped into subtopics which are arranged hierarchically, sequentially or for example in a circle

for each subtopic. In the end, this structuring can help to define he research endeavor more closely for which the review should provide the basis. This is because it shows how each subtopic is built-up and potential gaps and lacks research in one of these subtopics can be identified.

Another suggestion for a tool is introduced by Huff (2008) who recommend mind maps to structure a research topic in more detail. The difference between the mind map and the literature map is not the structure or the way of creating it, it is the content. In the mind map the topic is structured by several categories such as future research or important theories. The literature map on the other hand is more focused on those authors, whose publications contributed to the respective topics. Consequently, both approaches can be used complementary if both perspectives are required.

The last tool which is recommended is a reference management software (Booth et al. 2012). In this thesis for example Mendeley is used. However, there are several other examples of well-developed programs like Citavi or Zotero which basically all offer similar functionality. Today the use of such a system is obligatory since the vast amount of potentially available and interesting publications would be impossible to handle without the support of an organizing system. Furthermore, these tools have several additional features like taking notes, marking up PDF files or tagging which could facilitate as well as help to structure the scholarly work.

2.2.8 Recommendations

While the previous section provided recommendations for useful tools, the following aims at recommendations at a more general level. During the review process, several impediments can stand in the way of being successful at this endeavor. This section should provide some hints on how to overcome these impediments as well as avoid mistakes which could lower the quality of the results.

The discussion on which tense to use in the review process is two sided, since scholars argue for both the past tense and the present tense. In this thesis present tense is used, mainly for the reasons Webster & Watson (2002) provide in their article, which are the facilitation of the reading process, a feeling of immediacy from the reader's perspective and the fact that concepts, theories and methodologies in a review are discussed in the presents as it is traditional in the social sciences.

Reviewing literature is a time consuming effort, which is why it is necessary to set clear deadlines throughout the review process to not get lost during the project (Booth et al.

2012). Several obstacles like downtime of important databases or library services or even a slight change of research focus during the process can delay the whole process. These obstacles have to be considered. Therefore, it is recommendable to develop a well-considered project plan which includes buffers as well as other activities which can be implemented if for example the access to relevant literature is not possible at this moment.

Another recommendation, which is also highly relevant for this thesis is grouping the identified publications by research topic. In the article by Jourdan et al. (2008) this approach is used to classify Business Intelligence topics. In their project, several researchers contributed to this classification process through brainstorming and discussion sessions. In this thesis, the approach is similar since the definition of the research topics is performed in close cooperation with the supervisors.

The last important recommendation is a good documentation of the process a researcher used for conducting the review. There are several frameworks or methodologies which guide scholars through the review process. However, each research project is unique to a certain degree and additionally also each researcher brings his own experience into the project which can lead to adaptations in the process. The criteria used for selecting the right articles, the databases used for searching, the process of determining the relevance of a study, each of these important steps has to be described in detail to clarify the situation for the reader (Booth et al. 2012). The recommendations provided in this section are helpful for novice researchers and provide guidelines to handle the vast number of articles available on the Internet. Therefore, the recommendation will be overtaken into the approach in this thesis.

2.2.9 Cautions

Along with the recommendations in the previous section come cautions one has to consider during the review process, as well. All cautions mentioned in this section are already mentioned along this chapter. However, they can be helpful for structuring the literature review and handling pitfalls which could occur during the review process. Therefore, they are listed here once again because of their relevance.

One challenge of conducting a literature review is getting lost in the overload of information available today and mainly caused by the digitalization. The main problem is that a researcher has to find a middle course between the two extremes of obtaining and reading too much publications and missing out on potentially interesting information, which

could be caused by superficial surveying (Huff 2008). Huff (2008) also argues that finding the right time to stop the surveying process is key to the success of a research project since endless surveying can lead to missing the next step in the project.

Closely linked to the first caution outlined in the previous paragraph is the question, when to stop the literature reviewing process since there is no concrete threshold for doing so. However, one should consider the guidelines several authors like Okoli & Shabram (2010) or Levy & Ellis (2006) provided to avoid the danger of not finding the right point in time to end the reviewing. The guideline is that if a scholar recognizes the same concepts, results, methodologies or theories again and again and if he feels familiar with these, this could be a good point to end the review process.

The last caution mentioned in this chapter is the risk of the so-called scope creep which is a potential threat to every project not only in scientific endeavors. Scope creep is the risk of widening the scope of a project to a degree which is not reflected in the resources a scholar can spend on the respective project (Booth et al. 2012). This is important for the literature review as well. Therefore, a researcher should clearly define the limits of his topic to have a criterion for clearly deciding which article can be included topic-wise.

2.3 Implications of this Chapter for the Thesis

On several occasions in the previous sections implications for the practical part following in Chapter 3 and 4 are already insinuated. Section 2.1 defines the topic of railway safety in more detail and therefore forms guidelines for selecting which articles are included into the analysis. Section 2.2 describes the process of literature reviewing in detail and provides methodologies, recommendations as well as helpful tools.

The first section has two key takeaways which are explained in detail beforehand. One is that the decision whether a topic, which is included into the review, has to be evaluated with the question to which extent this research topic positively influences the safety of the overall railway system. Therefore, IT security is taken as an example. Researchers examining this topic in an industry context, as well, are also contributing to railway safety to some extent. However, these relations between improving IT security and railway safety are difficult to reveal, which is why, it is not included in the analysis. The same applies for researchers dealing for example with train conductor training. These are mainly psychologist however the relation of their research topics to technology which is the research focus of the CCRDMT is not given. Therefore, this topic is not included as well. One could argue that these decisions are arbitrary. Nevertheless, examining these

topics would create the problem that the scope of this project would exceed the available resources. Additionally, the examination of the related areas which are not included in this analysis could be a future research project for a thesis or a similar student project.

The second section offers several hints and advises for the reviewing process which can be useful in the following chapters. At first it has to be considered that a literature review like it is defined in this chapter is not conducted in this process. The review process is taken as a template and adapted to the goals which should be achieved in this thesis. Since the main goal is the identification of influential researchers, purposes of the classical review like identifying frequently used theories and methodologies fall out of the scope of this thesis. However, the structured approaches which are provided in Section 2.2.4 serve as a reference point for the review process in this thesis.

Additionally, Google Scholar, which is recommended by several books as well as journal articles (see Section 2.2.7) is chosen as the tool of choice for the identification and evaluation process. This is mainly because it covers every journal, conference or any other publications and is not limited to any discipline. This is an advantage in comparison to other proprietary databases, whose scope is limited to specific disciplines or publishers.

The most important part of this chapter for the overall project are the selection criteria. These criteria have to be used as guideline in this thesis as well since it is very important to decide if a publication is included in the analysis process. Therefore, the recommendations from other authors are used as a guideline for selecting the right criteria in Chapters 3 and 4.

Furthermore, the recommendations and cautions sections are helpful for conducting the practical part of this thesis. Reviewing literature is a sophisticated as well as comprehensive task. Therefore, there are several risks which can prolong or adversely affect a review project, especially the guidelines for scoping the review as well as finding the right point in time to stop will be inherited in this project. Additionally, the recommendation to classify the publications by topic as well as to document every step of the work carefully are applied in this thesis.

3 Identification and Categorization of Researchers and Universities

This chapter is divided into two parts. At first the process of identification of the railway safety researchers is introduced in detail. Furthermore, the practical implications which are collected throughout the identification process are described. When the process is finished the results of the identification are presented and illustrated in tables. This is especially important since this data forms the basis for the keyword analysis in Chapter 4.

3.1 Description of Identification Process

The process used to guide the identification process is aligned to the snowball principle which is already introduced in the section 2.2.5 since it is also an applicable method for identifying literature. To better understand how this systematic process has evolved a flowchart is used for illustration purposes, whose steps are described in this section in more detail.

Before starting the explanation of the process in detail, it has to be remarked that the process does not follow the goal of displaying the research area of railway safety in its completeness. This is neither the goal nor is it possible for a single researcher to achieve this goal. Therefore, this thesis tries to cover all major contributors to the research field. However, it cannot be guaranteed that one or two important researchers are not included in the analysis. This leaves open space for future research especially in bigger teams of researcher to, first try to cover the area in its completeness and afterwards go into more detail in each of the identified sub fields.

3.1.1 Aggregation of Information from Different Sources Part 1

For the identification of the most relevant researchers in the field mainly six information sources are used (see Figure 5), some of which are used in parallel during the inquiry, others are used sequentially. The process is started with an Excel list from a former CCRDMT student assistant, who already conducted a short overview of universities with focus on railway research[8]. All the universities in this table are checked on their currency and whether their research topics relate to railway safety. How this check is performed, has already been described in Chapter 2.

[8] This table can be found in the appendix.

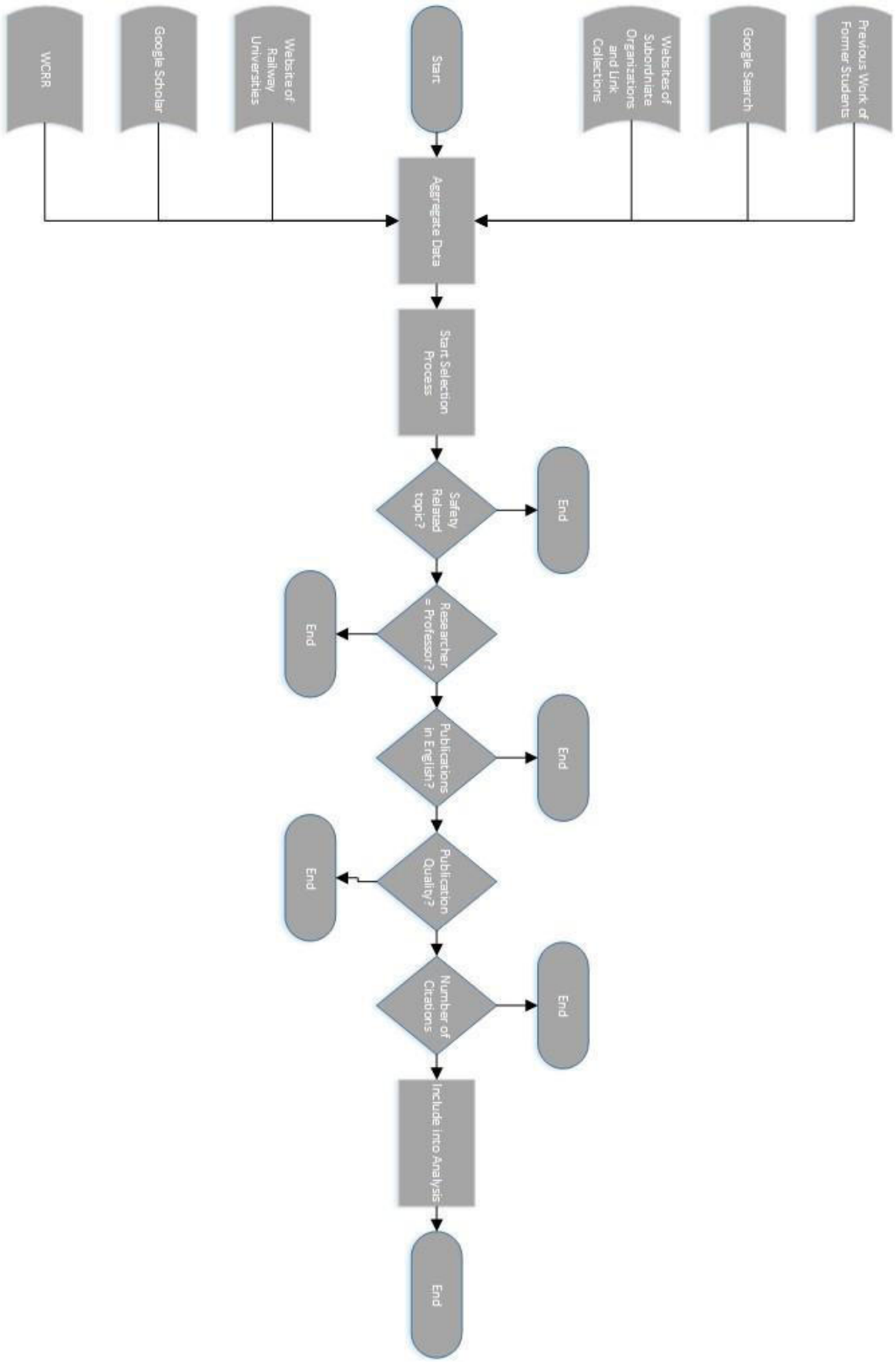

Figure 5: Flowchart of the Identification Process (Own Diagram)

After processing this file, 27 universities are aggregated in the Excel file which is used as a basis for this chapter. As a next step a classic desk research process is introduced to add up on the already existing list. The main goal of this step is to broaden the view over the topic. This is mainly achieved by looking for universities which are listed on the first few sites of the Google Search as well as looking for subordinate organizations like the UIC[9] or the Rail Research UK Association[10]. These subordinate organizations as well as the websites of very important railway research universities and institutions have the advantage that they aggregate information on other institutions which are not yet included in the analysis. Since these organizations are especially important for the CCRDMT – because they not only aggregate important information but also foster exchange between research and practice – they are introduced in more detail in the following. This introduction provides implications for future research at the CCRDMT as well as a basis for evaluation if a participation in one of these organizations could be beneficial.

3.1.1.1 Eisenbahnlehre.org

Eisenbahnlehre.org is a website established by sixteen German speaking universities which focus on railway or public transport in one or more of their departments (Verkehrswissenschaftliches Institut an der Universität Stuttgart e.V. 2010). Currently, ten German, three Austrian, two Swiss and one Dutch universities are part of this network. Their main goal is to attract high school graduates to one of their study programs which is related to railway transport. The reason for that is the constant growth of the public transport sector which enables promising career opportunities for graduates of these programs. Additionally, the website is helpful for the categorization process since it provides an overview of the study programs offered at these universities which are related to railway research. The 33 study programs introduced on the website show how diverse the field of railway research is and how complex it can be to allocate a researcher or a research facility to a specific category. From a current perspective, this network seems not to be very active since the last changes to the website were realized in 2013. However, the approach of networking teaching institutions for future employees in the railway sector is promising, especially because of the difficulty of finding young qualified employees for the industry.

[9] For further information on the research activities of the UIC see: www.uic.org

[10] For further information on the research activities of the UIC see: www.rruka.org.uk

3.1.1.2 Railway Technical Research Institute

The Railway Technical Research Institute (RTRI) is a research company which was incorporated as a consequence of the privatization process of the Japanese National Railway (Railway Technical Research Institute n.d.). They are funded by the Japanese state as well as the privatized railway operators evolving from the former state-owned company. Their main activities are at the interface between research and practice. They do both test and develop new railway technology as well as publish papers on new developments in the railway sector. As a long-term goal, they want to improve the safety as well as the quality of the transportation process with their research. Their website is helpful for two reasons. On the one hand, they provide a comprehensive list of other railway research institutions from all over the world, which can be used for this thesis. On the other hand, Germany and other European countries are lacking these large industry-research partnerships. This brings up the questions why Germany for example does not have a comparable institution. The RTRI could therefore serve as an example for creating similar organizations in other countries.

3.1.1.3 Railway Research UK Association

Just like the RTRI the Railway Research UK Association (RRUKA) is a network which should connect industry with railway researchers (Railway Saftety and Standards Board n.d.). The network was established and funded by the Railway Safety and Standards Board[11] (RSSB), an organization to promote and ensure railway safety in Great Britain. The main goals of the association are facilitating knowledge transfer between industry and research as well as supporting and identifying new research topics for the participating universities. Applying for membership in the association is open to all British researchers dealing with a railway-related research topic. The diversity of disciplines of the already participating members illustrates again how widespread this research field is. Presently, 53 institutional members are part of the network which shows its significance and makes it attractive for new members. In opposite to the German Eisenbahnlehre.org platform, the content on RRUKA is updated frequently.

3.1.1.4 International Railway Research Board

The International Railway Research Board (IRRB) is an organization established by the UIC in 2005 to foster joint activities between researchers and the UIC members

[11] See: www.rssb.co.uk

(International Union of Railways (UIC) n.d.). Since the UIC comprises 197 members across the globe, it is important to exchange knowledge as well as current research activities between these members. The IRRB should not only foster this goal but also additionally provide funding for joint research activities. Currently, the IRRB consists of 22 institutional members from multiple countries. On the website, no information on the current activities of the IRRB can be obtained. However, the participating research centers are highly active institutions.

3.1.1.5 National University Rail Center

The National University Rail (NURail) Center is a network of seven academic institutions in the United Sates, aspiring to foster the advancement of rail transportation in North America (University of Illinois at Urbana-Champaign n.d.). These seven institution are complemented by 16 affiliate institutions which are also conducting research and education for the railway sector. The main goals of the consortium are fostering workforce as well as academic education for future railway engineers, enabling technology transfer between academic institution and private industry companies and facilitating cooperative research. The Center is highly active until today and offers a regular annual meeting, workshops and on-sight visits in addition to its other activities for its members.

3.1.1.6 Railway Talents

Railway Talents is a platform which was set up by the UIC to recognize and foster talent in railway research institutions worldwide (International Union of Railways (UIC) n.d.). Since the railway sector already has problems in finding new talented employees, the network should foster institutions which have or plan to set up education programs for railway engineers. Furthermore, it should also form a career platform for young graduates and enable international cooperation between the participants. To do so “Rail Uni Net” was set up. This network of railway engineering education institution is coordinated by Newcastle University. It fosters cooperation between the participating universities as well as enables the exchange of talent. Therefore, they offer regular activities like workshops, student exchange or summer schools and engage in cooperative projects. Currently, 20 universities are participating in this network

3.1.1.7 Cooperative Research Centers Australia

The Australian government established the Cooperative Research Centers (CRC) in the 1990s to foster industry-research collaboration (Department of Industry Innovation and

Society n.d.). Out of this promotional program two railway-related CRCs were established. One is the CRC for Rail Innovation which was formed 2007 by seven leading Australian universities in this area (CRC for Rail Innovation n.d.). One of their six main research themes is fostering safety and security of railway transport which is closely related to this thesis as well as the CCRDMT's research focus. The second center is called "Rail Manufacturing CRC" whose research focuses on issues in the rail manufacturing industry in Australia. While the first CRC is more focused on improving rail transport in Australia, the Rail Manufacturing CRC wants to improve the competitiveness of Australian enterprises on the railway market. Therefore, eight universities and eight manufacturing companies form this research center which has a comprehensive program with focus on diverse research disciplines.

3.1.2 Aggregation of Information from Different Sources Part 2

After having identified these subordinate organizations, it can be observed that the pool of universities is substantially bigger. Additionally, some of the websites of highly recognized railway universities provide links to other universities which are also used for creating the aggregation table. After this process is finished, the focus is switched to the actual publications of these researchers. Therefore, Google Scholar is used as the platform for finding the relevant articles. The reason for that is that Google Scholar allows finding publications independent from the discipline. Therefore, it is well-fitting for achieving the objectives since railway safety is a multidisciplinary research field. The approach for identifying the publications is simple. On the universities' website, which are identified until now, the staff list is consulted to find all relevant railway researchers from the respective institution. After that the name is put into Google Scholar to find out if and how much this researcher has published. This also offers the chance to identify additional researchers and by looking through the co-authors. This approach also contributed to enhancing the aggregation list. As a finishing step in the aggregation process the SPARK Database[12] is used. On this database, which was developed by RSSB in cooperation with UIC and IRRB, one can find all kinds of railway-related publications, scientific as well as industry. SPARK is used because it aggregates and indexes all publications from the past World Congresses of Railway Research (WCRR) conferences. According to the UIC the WCRR is the leading international event for rail research and by number of participants the biggest meeting of rail researchers all over the world (International Union of

[12] For further information on the SPARK database see: www.sparkrail.org

Railways (UIC) n.d.). The benefits of this event are that the research topics covered are so diverse that a full overview of railway safety topic as it is defined in this thesis can be achieved. There are other approaches for achieving the same goal. However, these approaches are too time consuming for the timeframe of this thesis and therefore have to be postponed to future research. For example, the highly-ranked journals for each discipline like the Journal of Nature Materials for mechanical engineering could be scanned for railway publications for influencing and highly cited articles. This task however should be completed by a research team since it presents too much effort for only one researcher and two should be double checked by two researchers because of the vast amount of information. This information overload is avoided by limiting the sources for obtaining publications in this thesis.

Resulting from this aggregation process a list of 105 universities is put together[13]. In the next step the list goes through a selection process which is explained in the following section.

3.1.3 Selecting the Researchers

The process with the selection criteria of each step is illustrated in Figure 5. These steps are applied to each university and each of the respective researchers which are identified from this university. In some cases, all researchers of a university could be excluded from the analysis since the topic of the research did not fit into the railway safety field as defined in this thesis. To be included into the analysis all the criteria which are explained in the following paragraphs have to be fulfilled. This is also reflected in the attached Excel table. If one of the criteria is not met by a university and its researchers the others are not checked anymore since they do not meet the requirements set up for this analysis.

At first the research topic of each of the identified researcher is checked if it relates to railway safety, which has been defined in section 2.1. In several cases, it is difficult to decide if a direct connection to the topic of railway safety exists. Therefore, the limitation of the included researcher is very important to narrow the scope of the analysis to a manageable workload. As already explained with the example of psychology or IT security, which are both not included in the analysis, a direct connection between the improvement of railway safety and the research topic has to exist. Therefore, topics like improving energy efficiency, capacities or time tables of railway are excluded from the analysis.

[13] This list can be found in the appendix.

Several public transport researchers such as the Institute for Transport Planning and Systems from ETH Zurich deal with these topics because they are very important from an economic perspective. However, the present analysis is closely related to the GRADE database and the accident causes included in there. Consequently, the leading question for deciding if a university and its researcher(s) should be included is: Does the research topic directly influence the prevention of these accident causes?

Secondly, the role of the academic rank of the identified researcher has to be considered. In the following analysis, only professors and associate or assistant professors are considered. This selection is done for two reasons. The first and most important reason is to ensure the quality of the publications. Since becoming a university professor is tied to comprehensive selection procedure, in which the applicant has to prove the quality and relevance of his academic work, this criterion is strong and facilitates the quality assurance procedure for this thesis. However, this strict rule has also a downside: not being in the rank of a professor does not mean in all cases that the research is any less relevant or substantial. Therefore, it could also lead to leaving out some publications which are relevant as well. But the percentage of relevant publications which are not authored or co-authored by professors is relatively small. Hence the strictness of this criterion is reasonable from a quality perspective. Another benefit of this selection criterion is the narrowing of the scope, which is achieved by excluding for example lecturers or research associates. This ensures that the workload of this thesis is feasible for one person. In a bigger team of researchers this criterion could be dropped and each of the researcher could be checked individually if his work is relevant and/or influential.

The third selection criterion is the language of the publications as well as the website. Since internationally accepted research has to be published in English and every important formats of publications with international standing are publishing in English, this is an obligatory requirement. Additionally, the website of the university and the respective research group of the researchers should be available in English as well. This has two reasons. First, identifying the researchers on a website in the respective native language is not possible for the author who has only English and German language proficiency. Second, if an institute or research group does not offer the information in English, it shows that they lack international orientation. This is a strong exclusion criterion for this research project since finding potential research partners for the CCRDMT as well as for a new research network requires openness to international collaboration.

As a fourth criterion, the quality of the publication has to be considered. Therefore, section 2.2.6 is consulted which deals with criteria for selecting publications to be included in a literature review. In the following section, it is recommended to include published books, journal articles as well as conference papers, which are also included in this research project. The only difference is that in a classical literature review only the most relevant and influential articles should be considered. Here the focus is on researchers and not on the articles itself. Therefore, a differentiation which values journal articles higher than published books for example does not have to be undertaken. The limitation to these three types of publication is important since in railway research it is common to publish in industry journals or magazine which are neither peer reviewed nor stand elementary scientific standards like independence of science from external influence.

The fifth and last criterion is the citation frequency of the researcher's publications. According to Hart (1998), who wrote a highly influential book on the topic of literature reviewing, the number of citations is one of the most significant quality indicators for a scientific publication. If other researchers pick up the concepts or reference to the same article multiply, this shows the high influence of the work. Based on this a so-called relevance tree can be developed which shows an influential article on the top and how it was cited by other important articles in the same research field. For this thesis, the minimum number of citations for an article to be considered in the analysis is five, which is relatively low. However, since the publications origin from different research fields, it is a suitable common ground which can be agreed upon. This is mainly because the frequency of citations highly depends on the discipline. Since this thesis includes researchers from several different disciplines the citation practice also highly varies between them. An example would be mechanical engineering. If researchers investigate social science such as economics, influential researchers like M.E. Porter have citation numbers which are five- or even six-digit[14]. In mechanical engineering the citation rates are several times lower because the number of publications and the publication practice is not comparable. Summarized the simple rule for this selection process is that a researcher has to have at least one publication which is cited more than five times to be considered in the analysis.

Referring to section 2.2.6 it is also recommended to consider the year of publication since in several disciplines, it is important if for example the theories, concepts or technologies presented in the publication are still up to date. This criterion is not applied in this thesis.

[14] See: https://scholar.google.de/citations?user=g9WIbh0AAAAJ&hl=de&oi=sra

The main reason for that is already explained in the previous paragraph. The researchers considered in this thesis arise from different disciplines and additionally the railway safety topic in this thesis is reflected from different perspectives. Therefore, it is not easily possible to differ if the year of publication is or is not a relevant criterion. Consequently, the year of publication is not considered in the next section, which rather shows the results and the categorization process applied after all universities and researchers which fulfil the selection criteria are gathered.

In the following table, the results of this selection process are displayed. All identified universities are listed and if a university is not included into the analysis a short comment is provided to explain how this decision was made. For the number of citations, it has to be regarded that the numbers are taken from Google Scholar. Since these citation numbers increase rapidly, all the numbers listed in this table will probably be outdated already at the time this thesis is printed. The reference week for the collection of the numbers is week number 23 of 2017. A detailed description of each individual decision if a researcher and/or his university is not provided because it would exceed the scope of this thesis. For a better traceability, the spelling of the universities from the German speaking countries is retained in German since this makes the identification easier for future researchers building upon this work. In Table 5 105 universities are listed which are selected from the previously explained sources.

Table 5: Identified Universities According to Selection Criteria (Own Table)

University	**Safety Related Topic**	**Academic Rank**	**Language**	**Publication Quality**	**Number of Citations**	**Exclusion Criterion**
A Coruna	Y	Y	Y	Y	Y	
Aachen	Y	Y	Y	Y	Y	
Ajou			N			Language barrier
Alberta	Y	Y	Y	Y	Y	
Bath	Y	Y	Y	Y	Y	

Belgrade					N	Number of citations <5
Berlin	Y	Y	Y	Y	Y	
Birmingham	Y	Y	Y	Y	Y	
Boise	Y	Y	Y	Y	Y	
Braunschweig	Y	Y	Y	Y	Y	
Brunel University London					N	Number of citations <5
Bucharest	Y	Y	Y	Y	Y	
Cambridge	N					Influence of rail vibrations on buildings as research topic
Central Queensland University	Y	Y	Y	Y	Y	
Centre for Railway Research Indian Institute of Technology Kharagpur					N	Number of citations <5
Chalmers	Y	Y	Y	Y	Y	
Chicago	N					Transport systems in general as research topic
Chinese Academy of Railway Science			N			Language barrier through not translated websites
Cottbus	N					
Cracow					N	Number of citations <5
Darmstadt	N					Transport planning as research topic

De Montfort University	Y	Y	Y	Y	Y	
Delft	Y	Y	Y	Y	Y	
Dresden			N		N	Number of citations <5; predominantly German publications
Ecole des Ponts Paris			N			Language barrier through not translated websites
Edinburgh	Y	Y	Y	Y	Y	
Estaca			N			Language barrier through not translated websites
Florence			N			Language barrier
Genoa					N	Number of citations <5
Graz	Y	Y	Y	Y	Y	
Hartford	Y	Y	Y	Y	Y	
Heriot-Watt University	Y	Y	Y	Y	Y	
Huddersfield	Y	Y	Y	Y	Y	
Imperial College London	Y	Y	Y	Y	Y	
Kaiserslautern	N				N	Number of citations <5; Transport planning as research topic
Karlsruhe	Y	Y	Y	Y	Y	
Lausanne	Y	Y	Y	Y	Y	

Leeds	N					Transport systems in general as research topic
Leuven	Y	Y	Y	Y	Y	
Lille			N			Language barrier through not translated websites
Lisbon Tecnico	Y	Y	Y	Y	Y	
Liverpool	Y	Y	Y	Y	Y	
Loughborough	Y	Y	Y	Y	Y	
Lovaine	Y	Y	Y	Y	Y	
Lulea	Y	Y	Y	Y	Y	
Madrid Polytecnic	N					Competition between transport systems as research topic
Manchester Metropolitan University			N			Website offline
Melbourne La Trobe	Y	Y	Y	Y	Y	
Milan Politechnico	Y	Y	Y	Y	Y	
Minho	Y	Y	Y	Y	Y	
MIT	N					Competition between transport systems as research topic
Monash University	Y	Y	Y	Y	Y	
Moscow State University of Railway Engineering					N	Number of citations <5

München					N	Number of citations <5
Naples	N					Competition between transport systems as research topic
Nebrija University	Y	Y	Y	Y	Y	
Newcastle	Y	Y	Y	Y	Y	
Norwegian University of Science and Technology	Y	Y	Y	Y	Y	
Nottingham	Y	Y	Y	Y	Y	
Penn State Altoona	Y	Y	Y	Y	Y	
Petersburg State Transport University					N	Number of citations <5
Porto	Y	Y	Y	Y	Y	
Prague					N	Number of citations <5
Pretoria	Y	Y	Y	Y	Y	
Queensland University of Technology	Y	Y	Y	Y	Y	
Rome (Sapienza)	N					Time table optimization and capacity planning as research topics
Rome (Tor Vergata)	Y	Y	Y	Y	Y	
Salford	Y	Y	Y	Y	Y	
Sao Paulo	Y	Y	Y	Y	Y	
Seoul					N	Number of citations <5

Sheffield	Y	Y	Y	Y	Y	
Siena	Y	Y	Y	Y	Y	
Southampton	Y	Y	Y	Y	Y	
St. Pölten					N	Number of citations <5
Stockholm	Y	Y	Y	Y	Y	
Stuttgart			N		N	Number of citations <5; predominantly German publications
Swansea	Y	Y	Y	Y	Y	
Taiwan	Y	Y	Y	Y	Y	
Tampere	Y	Y	Y	Y	Y	
Technion			N			Search on website unsuccessful
Teheran	Y	Y	Y	Y	Y	
Texas A&M University			N			Search on website unsuccessful
The University of Tennessee Knoxville	Y	Y	Y	Y	Y	
Tokyo	Y	Y	Y	Y	Y	
Turin Politechnico	Y	Y	Y	Y	Y	
University College London	N					Transport systems in general as research topic
University of Cali San Diego	Y	Y	Y	Y	Y	
University of Delaware	Y	Y	Y	Y	Y	

University of Essex	N					Privatization of railway as research topic
University of Illinois at Urbana-Champaign	Y	Y	Y	Y	Y	
University of Kentucky	Y	Y	Y	Y	Y	
University of Michigan	N					Logistics and material science as research topic
University of Navarre					N	Language barrier
University of Queensland	Y	Y	Y	Y	Y	
University of Surrey	Y	Y	Y	Y	Y	
University of Sussex		N				Researcher is not a professor
University of Texas Rio Grande	Y	Y	Y	Y	Y	
Valenciennes			N			Language barrier through not translated websites
Warsaw	Y	Y	Y	Y	Y	
Wien	Y	Y	Y	Y	Y	
Wollongong	Y	Y	Y	Y	Y	
Wuppertal					N	Number of citations <5
York	N					Railway history as research topic
Zaragoza			N			Search on website unsuccessful

Zürich	N					Transport systems in general as research topic

Out of these 105 universities 59 fulfilled all five criteria to be included into the analysis in the next chapter. There are mainly four reasons why a university could not be regarded in the analysis. These reasons are shortly stated in the column. To get a better understanding of these reasons and to provide a common knowledge basis for future researchers, these reasons are explained in the following paragraphs in more detail.

The first and most frequent reason is that the researchers are not fulfilling the predefined minimum number of citations. That means that none of their publications is cited more than 5 times according to Google Scholar. This could happen for several reasons; one reason is that they mainly publish in their native language and their English publications therefore are minor and lack of relevance. Additionally, some of these researchers are highly engaged with other activities as one can recognize from their websites. Especially cooperation with industry partners as well as teaching activity can hinder these researchers from publishing more frequently. Particularly in small research group with less than five employees the researchers can be so focused on teaching that they lack additional time for publishing their research. Furthermore, smaller universities are also facing the problem of an insignificant standing in the scientific community. This makes it difficult for researchers from these universities to compete with large and prestigious universities like Birmingham or Milan who are known all over the world for their excellence in railway research.

The second reason which lead to exclusion from further analysis is that the research topics of the respective university lacks relation to railway safety as understood in this thesis. These universities were identified during the investigation process since their topic relates to railway research in general. However, they deal with for example competition of railway to other transport systems, time tabling and capacity planning, or privatization of railway. From these excluded topics one can recognize that, although the railway safety topic is already broad and multidisciplinary, railway research in general is an even more diverse field of research.

The third reason is the language barrier, which is reflected both in the language of publication and/or the language of the website. Universities whose researchers only publish in

their native language are not included in the analysis since their publications lack international relevance. Additionally, several universities especially from Asian countries do not have well-translated websites. The front page of the university is translated to English in most cases. However, when trying to enter the websites of the departments on which to find the relevant researchers, these websites are not translated to English. The same applies for French and some Eastern European universities. This does not mean that these universities lack relevant research, but it is not possible to identify the respective researchers, a step, which is obligatory for the analysis in section 3.2. Thus, excluding these universities is indispensable in this thesis. Nevertheless, future researchers who are able to understand these languages could extend the analysis by these universities.

The fourth reason which frequently lead to an exclusion from the analysis is that it is not possible to identify a researcher, department or institute at the website of the university, which explicitly deals with railway research. The reason why these universities are on the aggregation list in the first place is that some of the websites of the subordinate organizations list these universities as railway research institutions. However, using Google, the website navigation and internal research on the websites of the respective universities does not lead to any relevant results. This could have various root causes. One could be that the website is developed so substandard that neither the navigation nor the search functions can lead to sufficient results. Another reason could be that the researcher or research group is no longer working respectively does no longer exist at this university.

3.2 Categorization and Ranking of Researchers

In this section two steps are conducted. At first a method for categorization of the universities and the respective researchers is developed. Secondly, a method for ranking each of the researchers and their university by their relevance is introduced and then applied to the selected universities which are illustrated in Table 5.

3.2.1 Categorization Method and Distribution Analysis between Categories

Categorizing the 59 universities which are left after the preselection in section 3.1, is a complex task since the research topics of the universities are highly diverse. Therefore, it is difficult to decide on the number of categories. The problem is that if 30 categories are developed, there would be only averaged 2 universities per category. This would not be a well-conceived approach since the researchers should be ranked in each category and not overall. This is because comparing researchers from two completely opposite research fields does not make any sense. Since this thesis is a first approach on ranking researchers

and universities in railway safety research a small number of categories is appropriate. This is because increasing the level of detail always means that one can get lost in the details and resulting in missing the overall insights which could be drawn from a simpler analysis. Therefore, the disciplines of the researchers are used as categories in this thesis. This categorization method bears advantage that the allocation of the researchers is in most cases unambiguous since the researcher's discipline can be easily obtained from his personal website or the institute he belongs to. The result of this categorization process is illustrated in Table 6.

As presented in this table six disciplines are identified for categorization. In Figure 6: Distribution of Disciplines between Selected Universities (Own Diagram)Figure 6 the distribution between these categories is displayed and shows that two major categories, mechanical and civil Engineering, and four minor categories are identified. The reasons for that are obvious. The railway system overall consists of two parts. One is the track and the other is the rolling stock. Civil engineers deal with the development of the track-bed, the rails and the superstructure in general. Furthermore, they are involved in planning the construction of new railway tracks. For doing so they also have to consider the geological circumstances and the environment which could influence the condition of the railway track.

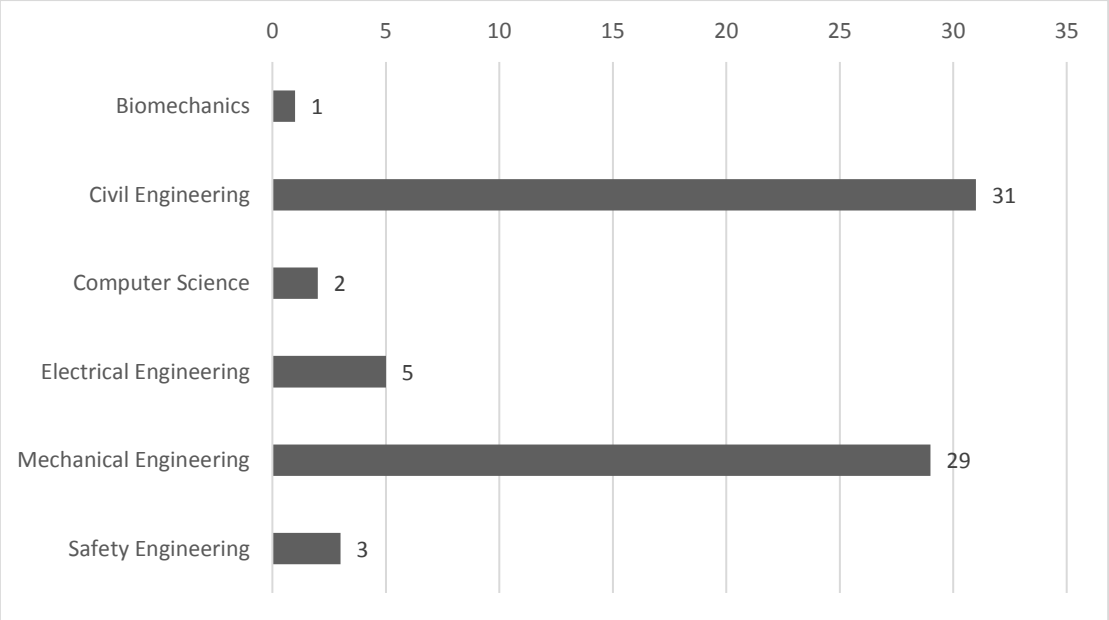

Figure 6: Distribution of Disciplines between Selected Universities (Own Diagram)

Additionally, they also deal with the wheel-rail interface and how the rolling stock stresses the superstructure. This area of responsibility makes civil engineers an important

contributor to railway safety. Mechanical engineers are by the nature of their discipline mainly responsible for the development of the rolling stock. Therefore, they deal with the improvement of railway vehicles, developing new and better trains as well as integrating new technologies into modern trains. However, through digitalization and new developments in powertrain technology the train as system has become more complex over time while multiple other disciplines are also influencing the development of modern trains. Nevertheless, railway vehicle engineering, which is a study program at multiple university, is a sub-discipline of mechanical engineering by its historic development. Therefore, most of the researchers in this field are closely related to the mechanical engineering research field.

The additional four categories have minor influence on the field because they cover edge areas of the railway safety research field. The most important of these four is electrical engineering which deals with the different ways of transmitting power to the trains. This area is constantly changing through new developments in technology, which bring potential improvements for safety along. The safety engineering field contains researchers who deal with signaling, rail accident cause analysis or level crossing safety. These researchers are the closest to the overall topic by their origin because they have a direct focus on how to prevent or diminish the potential consequences of a railway accident. However, this research field seems to be neat. Accident cause analysis on the other hand is a bigger research field if the focus on railway accidents is not regarded. In the computer science category two universities with a strong focus on theoretical computer science are allocated. These researchers deal with the formal verification of a railway network. Nowadays utilization of railway network through passenger trains is growing, which makes it necessary to clock the trains closer (Deutsche Bahn 2017). Therefore, the risk of potential accident due to an overloaded railway network increases. Formal verification is therefore an indispensable condition for guaranteeing the safety of a railway network. The last category is a special case since it is only one researcher identified who deals with this topic. Andrew McIntosh from Monash University analyzes how human behavior influences the sequence of events during a railway accidents, thus investigating human errors and mistakes who contributed to the evolution of an accident. This is a very specific research field, but it is also an important aspect when thinking of increasing railway safety. Before

going into detail with the ranking and the presentation of the universities and their respective researchers, Figure 7 shows the distribution of the universities between the countries[15].

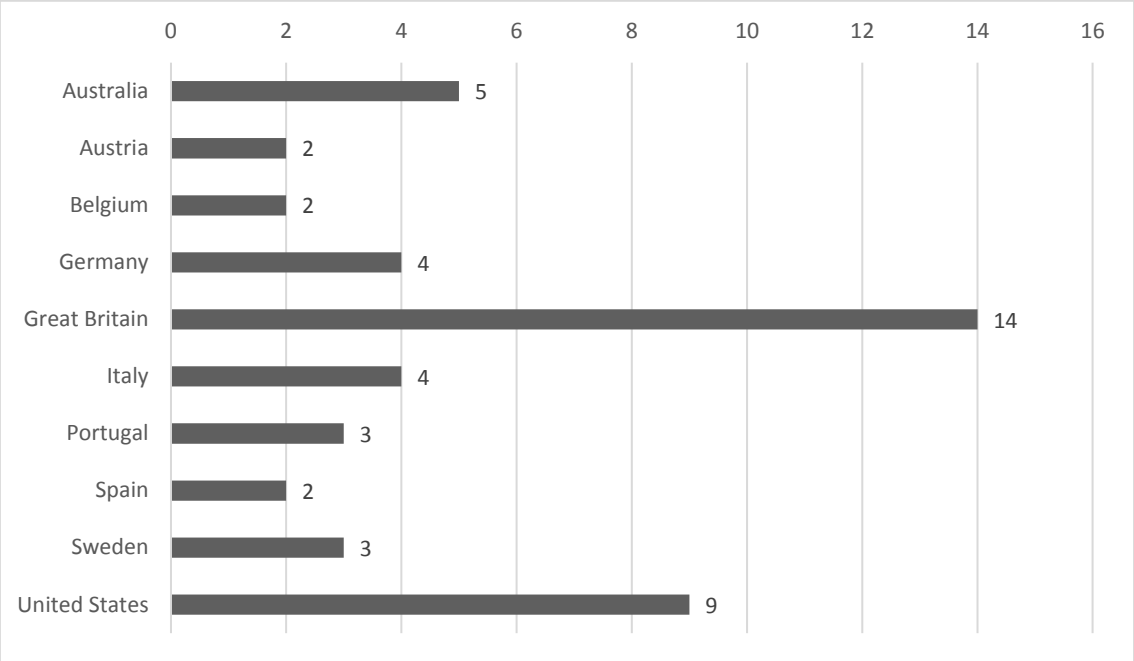

Figure 7: Distribution of Countries between Selected Universities (Own Diagram)

In the top position, Great Britain and the USA are listed with a noticeable gap to the other countries, which can be well justified by two reasons. First the most prestigious universities in the world are mostly located in these two countries (Schürmann 2017). Among the ten best universities in the world eight are from the United States and two are from Great Britain according to the THE ranking. Since these universities' prestige also attracts the best researchers, the high number of citations of publications from universities out of these two countries is comprehensible. Additionally Great Britain is also the country of birth of railway since the first railway track ever was opened between Stockton and Darlington in 1825 (Stephan & Aufmkolk 2017). This was the starting point for Great Britain's long railway engineering history which among others lead to founding of important organizations like the Institution of Mechanical Engineers (IMechE), which today host some of the most important conference for railway research. Following in the ranking is Australia which can be explained by the historic influence of Great Britain as well as

[15] The lack of Asian countries in this list is already explained previously through the language barrier.

seven other European countries with two to four selected universities. Countries with only one nomination are excluded from the diagram for clarity reasons.

3.2.2 Development of the Ranking Procedure

Based on Table 5's illustration of the selection process, in Table 6 an overview of all selected universities is provided and is enriched with more detailed information. The country and category, in the column "Research Area", are added. The analysis of these two columns is already presented in the previous paragraphs. Table 6 is developed based on an Excel file which is provided in the appendix. This Excel file not only includes the overview list as illustrated. It also comprises relevant information on each of the university's professors. For each university, an own Excel sheet is created which lists the name, research interests, research area, position and most importantly the five most cited articles of each researcher. As already implied in previous sections, ranking of the researchers which is one of the research objectives for this thesis has to be performed based on objective criteria. Using the five most cited articles serves as such a criterion. Evaluating the influence and the quality of a researcher and/or a university is a complex task. One method would be the approach from THE who conducted a survey among 10,500 researchers to identify the 100 top universities worldwide (Schürmann 2017). However, this method would exceed the capacity available for this master thesis.

Therefore, another approach has been developed. When professors apply for a professorship at a university several criteria are considered to find the best fitting candidate. In Germany, usually an appointments committee is created, which consists of current professors as well as employees and students of the respective university. In these committees the members are recommended to follow the subsequent criteria (Technische Universität Dortmund 2017):

- excellence in research and teaching,
- international orientation,
- publications in peer reviewed entities,
- relevance,
- experience with acquiring of research funding
- social and leadership competence.

Table 6:Ranking and Categorization of Selected Universities (Own Table)

University	Country	Research Area	Average Citations per Researcher	Number of Researchers	Overall Citations	#1	#2	#3	#4	#5	#6	#7	#8
Monash University	Australia	Biomechanics	233,00	1	233	233							
Leuven	Belgium	Civil Engineering	510,80	5	2554	855	707	460	424	108			
Wollongong	Australia	Civil Engineering	822,00	2	1644	1069	575						
Southampton	Great Britain	Civil Engineering	280,50	4	1122	707	235	147	33				
Porto	Portugal	Civil Engineering	279,75	4	1119	346	294	284	195				
University of Illinois at Urbana-Champaign	United States	Civil Engineering	250,67	3	752	323	269	160					
Birmingham	Great Britain	Civil Engineering	364,00	2	728	368	360						
Queensland University of Technology	Australia	Civil Engineering	361,00	2	722	425	297						
Heriot-Watt University	Great Britain	Civil Engineering	167,50	4	670	289	156	141	84				
Teheran	Iran	Civil Engineering	84,71	7	593	150	135	112	81	70	36	9	
Lulea	Sweden	Civil Engineering	86,25	4	345	132	100	73	40				
Edinburgh	Great Britain	Civil Engineering	261,00	1	261	261							
Taiwan	Taiwan	Civil Engineering	255,00	1	255	255							
De Montfort University	Great Britain	Civil Engineering	250,00	1	250	250							
Penn State Altoona	United States	Civil Engineering	87,50	2	175	145	30						
Pretoria	South Africa	Civil Engineering	173,00	1	173	173							
Hartford	United States	Civil Engineering	171,00	1	171	171							
A Coruna	Spain	Civil Engineering	51,00	3	153	59	50	44					
University of Delaware	United States	Civil Engineering	56,00	2	112	104	8						

Graz	Austria	Civil Engineering	35,67	3	107	77	21	9					
Nottingham	Great Britain	Civil Engineering	106,00	1	106	106							
University of Kentucky	United States	Civil Engineering	96,00	1	96	96							
Chalmers University of Technology	Sweden	Civil Engineering	94,00	1	94	94							
Lisbon Tecnico	Portugal	Civil Engineering	91,00	1	91	91							
Boise	United States	Civil Engineering	80,00	1	80	80							
Minho	Portugal	Civil Engineering	68,00	1	68	68							
Braunschweig	Germany	Civil Engineering	43,00	1	43	43							
Wien	Austria	Civil Engineering	36,00	1	36	36							
Norwegian University of Science and Technology	Norway	Civil Engineering	32,00	1	32	32							
Lausanne	Switzerland	Civil Engineering	29,00	1	29	29							
Karlsruhe	Germany	Civil Engineering	15,00	1	15	15							
Tampere	Finland	Civil Engineering	5,00	1	5	5							
Swansea	Great Britain	Computer Science	121,00	2	242	125	117						
University of Surrey	Great Britain	Computer Science	84,00	1	84	84							
Loughborough	Great Britain	Electrical Engineering	366,00	2	732	634	98						
Salford	Great Britain	Electrical Engineering	406,00	1	406	406							
Birmingham	Great Britain	Electrical Engineering	349,00	1	349	349							
Berlin	Germany	Electrical Engineering	89,00	1	89	89							
Teheran	Iran	Electrical Engineering	41,50	2	83	49	34						
Milan Politechnico	Italy	Mechanical Engineering	298,00	8	2384	543	409	343	311	251	240	171	116

Chalmers University of Technology	Sweden	Mechanical Engineering	393,83	6	2363	611	600	382	355	274	141		
Stockholm	Sweden	Mechanical Engineering	338,33	6	2030	571	539	351	294	246	29		
Huddersfield	Great Britain	Mechanical Engineering	400,67	3	1068	1068	122	12					
Delft	Netherlands	Mechanical Engineering	233,50	4	934	378	322	181	53				
Sheffield	Great Britain	Mechanical Engineering	380,50	2	761	429	332						
Lisbon Tecnico	Portugal	Mechanical Engineering	312,50	2	625	379	246						
Teheran	Iran	Mechanical Engineering	224,50	2	449	391	58						
Central Queensland University	Australia	Mechanical Engineering	205,00	2	410	230	180						
Turin Politechnico	Italy	Mechanical Engineering	95,50	4	382	116	102	102	62				
Heriot-Watt University	Great Britain	Mechanical Engineering	381,00	1	381	381							
Warsaw	Poland	Mechanical Engineering	111,67	3	335	209	83	43					
Siena	Italy	Mechanical Engineering	334,00	1	334	334							
University of Cali San Diego	United States	Mechanical Engineering	238,00	1	238	238							
Nebrija University	Spain	Mechanical Engineering	196,00	1	196	196							
Tokyo	Japan	Mechanical Engineering	193,00	1	193	193							
Southampton	Great Britain	Mechanical Engineering	183,00	1	183	183							
Nottingham	Great Britain	Mechanical Engineering	137,00	1	137	137							
Lovaine	Belgium	Mechanical Engineering	134,00	1	134	134							
Loughborough	Great Britain	Mechanical Engineering	133,00	1	133	133							
University of Queensland	Australia	Mechanical Engineering	109,00	1	109	109							
University of Texas Rio Grande	United States	Mechanical Engineering	92,00	1	92	92							
Bucharest	Romania	Mechanical Engineering	79,00	1	79	79							

Liverpool	Great Britain	Mechanical Engineering	66,00	1	66	66							
Sao Paulo	Brazil	Mechanical Engineering	60,00	1	60	60							
Berlin	Germany	Mechanical Engineering	51,00	1	51	51							
Newcastle	Great Britain	Mechanical Engineering	48,00	1	48	48							
Rom (Tor Vergata)	Italy	Mechanical Engineering	23,00	2	46	23	23						
Aachen	Germany	Mechanical Engineering	5,00	1	5	5							
Huddersfield	Great Britain	Safety Engineering	67,00	2	134	122	12						
University of Tennessee Knoxville	United States	Safety Engineering	85,00	1	85	85							
Braunschweig	Germany	Safety Engineering	26,00	2	52	34	18						

These criteria list serves as reference point for the evaluation process in this thesis. Some of these criteria are hard to measure like social competencies and relevance which is why they are left out of the analysis in this thesis. International orientation is already considered by looking at the publication language and the presentation on the website. Experience in research funding and especially industry collaboration, which is very important in railway research, is a good indicator of the quality of a researcher. However, there are two problems. On the one hand, it is difficult to identify which university and researcher is collaborating with which company, since this information is not always made public. On the other hand, the scope of collaboration, for example the yearly financial resources the industry partner provides, is not publicly accessible in most cases. Therefore, it would be difficult to rank researchers by this criterion. Excellence in research and teaching comes along with a similar problem. Finding objective and quantifiable indicators for measuring these two criteria is a complex task because evaluating the quality of teaching between different universities and even more complex countries could be sophisticated since the university education highly differs because of historically developed systems. All these counterpoints of the five other criteria on the list lead to choosing the publications as a quality and relevance indicator for the evaluation process in this thesis. As already pointed out beforehand Hart (1998) also mentions that the citation count is one of the most important indicators for the relevance of publication while its major benefit is that it is easily measurable since the information is publicly available through Google Scholar. Additionally, it is also easy to develop a ranking scheme since it is a numerical piece of information.

For this reason, the top five of the most cited publications of each identified researcher are gathered in the respective Excel sheet of their university (see appendix). The reasons for selecting five publications is mainly because it is a middle course between choosing too few or too many. If only the top one or two publications would have been selected, the selection would not have been representative. Especially researchers who are publishing rather little and have one highly accepted publication would be overrated in the ranking. On the other hand, also researchers, who try to publish as much as possible should not be included in contrast to those who do not focus on publishing. Therefore, selecting the top five of the publications is an appropriate choice for avoiding both risks.

The selection process is conducted via Google Scholar. If the respective researcher has created a Google Scholar account in the past, the identification of his most cited publications is simple since this database ranks them on the profile automatically. If that is not

the case, the researcher has to be identified via the usual search function. In several cases, additional information like adding the keywords “rail”, “railway” or “train” had to be provided to delimitate the researcher from other researchers with the same surname. It is important to include only railway publications since there are several researchers included in this analysis who also published in another research field. These publications are not of interest for this thesis. Therefore, each of the publications has to be checked manually by reading the abstract and the title to evaluate if the publication is railway-related. After this process is completed, for each of the researchers the number of citations of the top five publications is summed up individually and then for each university, as well. In Table 6 all these citation counts are summed up and the universities are already ranked top-down for each of the disciplines in the column “Overall Citations”. In the following columns “#1” and so forth sort the researchers from these universities by their overall citation count. Additionally, the number of researchers for each university in total is provided for a better overview. Furthermore, one column also lists the average citation count per university. This is because the overall citation bears the risk that universities with a larger number of professors are valued higher than smaller universities. Therefore, the smaller universities are also regarded by calculating the average citation count per researcher which is calculated through dividing the overall citations by the number of researchers.

In the first place, it could be confusing that some universities are listed twice or three times in Table 6. This is because some universities conduct research in different research areas and therefore are for example listed in civil as well as mechanical Engineering. These universities should also be higher regarded because it shows their broad spectrum of research, which could for example lead to progressive interdisciplinary research approaches.

In the following sections, the results of the ranking procedure are analyzed in more detail. Therefore, the top five civil engineering, top five mechanical and top three electrical engineering universities are introduced. For the reasons explained in the previous paragraphs this ranking is performed based on both average and overall citation counts. Since the validity of the ranking could be questioned because it is based only on one indicator, the citation count, an additional external variable for ensuring criterion-related validity is introduced: The top universities are checked concerning their place in the THE world university ranking for engineering and IT.

3.2.3 The Top Five Civil Engineering Universities

The top five universities in the category civil engineering by overall citations are listed in Figure 8. It is noticeable that all five of them originate from different countries and from three different continents.

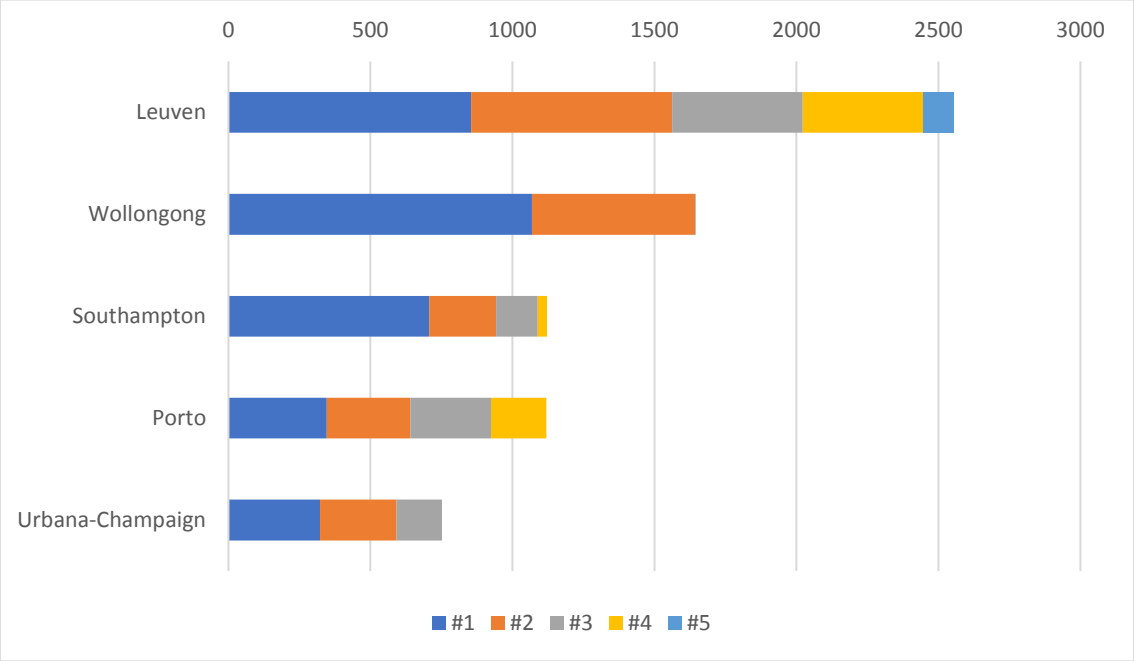

Figure 8: Five Overall Most Cited Civil Engineering Universities (Own Diagram)

This shows that the discipline is diversified and there is no real focus of the research field on one country or continent. Furthermore, the ranking is also relatively distinct besides the difference between Porto and Southampton which is only three citations. Due to this marginal difference the third place is shared between these universities. Leuven with the almost 1,000 citations achieved a clear first place as well as Wollongong distances the shared third place clearly by almost 500 citations. The University of Illinois at Urbana-Champaign reached the fifth place but is followed with no clear distance (around 20 to 30 citations) by the University of Birmingham and Queensland University of Technology. Since the citation count is a highly dynamic number which can change daily, a small difference like this lack significance. The ranking is now checked back with the THE ranking. Out of the five universities which are identified as the top civil engineering universities for railway research, three appear in the THE ranking. Leuven is ranked 34, Southampton 92 and Urbana-Champaign appears on rank 16. The difference in the order of the THE ranking in comparison to the ranking in this thesis is explainable since THE is not focused on civil engineering as a single discipline but on all engineering and information technology specializations. Overall having three of five universities in the top 100

worldwide indicates that the ranking procedure applied in this thesis is significant. The appearance of the two other universities is also explainable. Wollongong appears on the list with good reason. On the one hand Buddhima Indraratna, the director of the Research Centre for Geomechanics, is one of the experts when it comes to controlling the geological influence on railway track. Additionally THE ranks Wollongong, founded in 1951, among the top 30 young universities worldwide (University of Wollongong n.d.). Porto is ranked between place 400 and 500 in the THE university ranking. However, the iRail project[16] is a large cooperative research program between three Portuguese and Brazilian universities with around 50 researchers working together on innovations in the railway sector. University of Porto is the main contributor in this project which justifies their high ranking.

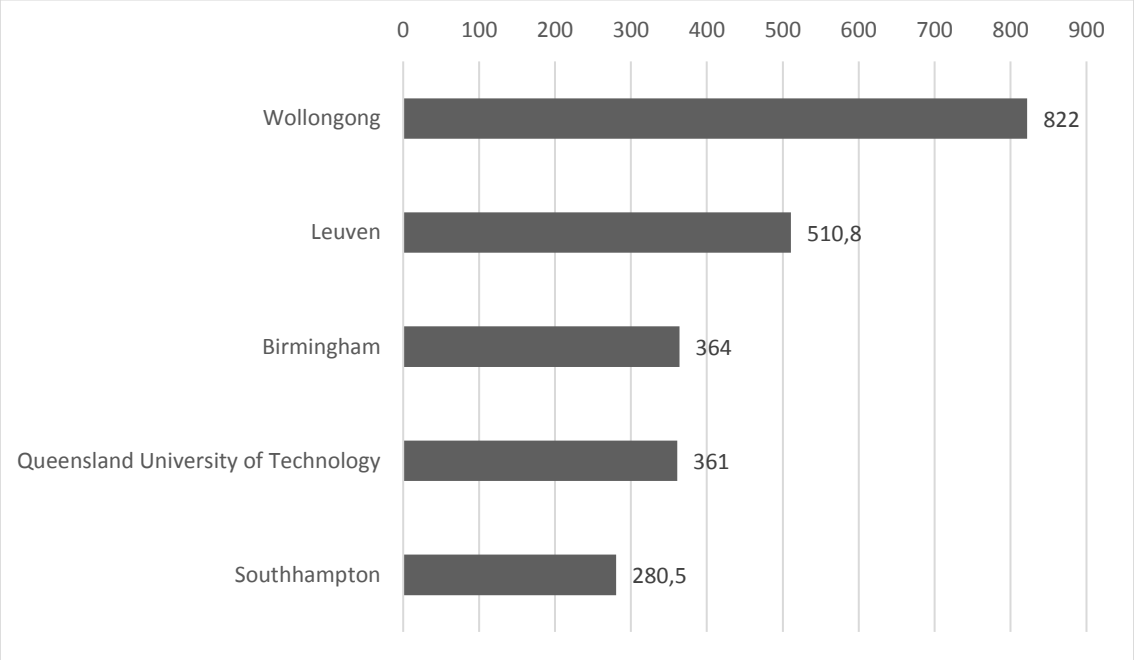

Figure 9: Top Five Civil Engineering Universities Based on Average Citations (Own Diagram)

As already pointed out in this chapter the number of overall citations should not be a single criterion without any further detailed evaluation since universities – respective departments or institutes – with more researchers in the rank of a professor are favored to smaller research groups. Therefore, Figure 9 displays the top five universities based on average citations. Three of the five universities from the overall ranking are still among the top five. However, Porto and Urbana-Champaign disappeared and are only ranked

[16] For more information see: https://web.fe.up.pt/~irail/

sixth (Porto) and ninth (Urbana-Champaign). Newly appearing are Birmingham and Queensland University of Technology (QUT), which are on the sixth and seventh place in the overall ranking.

Furthermore, Wollongong and Leuven switched places on the top because the research group at Wollongong only consists of two professors in comparison to the four professors at Leuven which makes the individual citation count significantly higher for Wollongong. Again, the ranking between the first, second and third place is distinct with clear distance between the places. However, Birmingham and QUT are so close together that again a shared third place is appropriate. Porto which is now ranked sixth is also only in one citation distance to Southampton, so fifth place is also shared. Places 7 to 10 differ by 10 in citation count which is a marginal difference, as well. Therefore, these do not differ largely in their relevance.

Overall the comparison of average citation rankings with overall citation rankings shows that the latter is already a well-chosen indicator since the first seven universities from the overall ranking also appear among the top ten in the average citation ranking. Additionally, the changes in positions which are already compared in the previous paragraph are minor. Summarized the overall ranking is validated by the average citation ranking.

This ranking is only a starting point for a further and more detailed analysis of each of the universities, their researchers and research fields. This analysis would exceed the scope of this thesis and therefore leaves room for future research endeavors.

3.2.4 The Top Five Mechanical Engineering Universities

In this section the top five mechanical engineering universities in railway research are presented and analyzed based on the overall and the average citation count. The top five ranking for the overall citations is illustrated in Figure 10.

While in civil engineering three different continents and five different countries are ranked among the top five based on overall citations, in mechanical engineering there is a clear focus on Europe with all five universities originating from one continent. The countries however are still equally distributed with a small focus on Sweden which occupies rank two and three.

The ranking of the five universities is distinct besides place one and two. Milan Politechnico and Chalmers University of Technology are only 21 citations apart which gives them a shared first place. Due to the marginal difference and additionally the highly

dynamic development of the citation count a shared first place is appropriate. The following places are also clearly distributed. However, Stockholm is much closer to the second place than Huddersfield is to the third. This makes the first three the leading group in mechanical engineering with clear distanced runner-up's. Delft also distances the sixth place Sheffield clearly, which makes the top five listing in Figure 10 explicit.

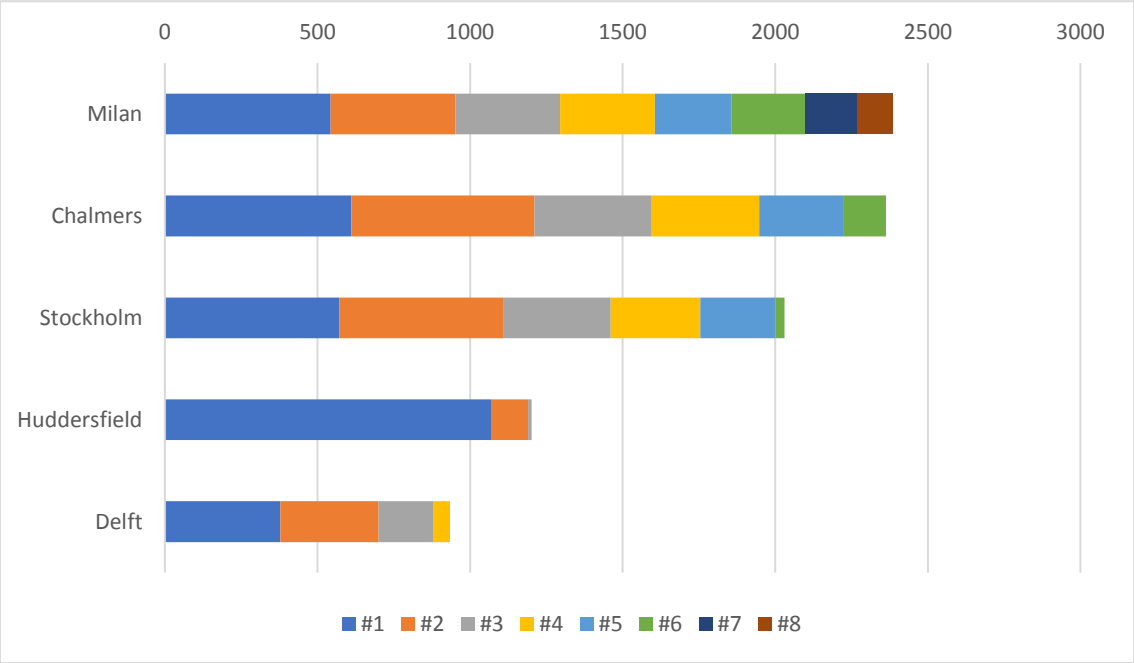

Figure 10: Five Overall Most Cited Mechanical Engineering Universities (Own Diagram)

As a next step the ranking is checked for conformity with the THE ranking. For mechanical engineering the conformity is even higher than for civil engineering since four out of the five are also among the top 100 universities worldwide in engineering and IT. Milan reaches place 82, Chalmers place 76, Stockholm place 36 and Delft place 20. By coincidence the ranking from THE is in reverse order to the ranking in this thesis. The reason for that is already explained in the previous section since the THE ranking does not investigate mechanical engineering in specific but all engineering and IT specializations. Again, the appearance of these four out of five universities makes the ranking justifiable. The University of Huddersfield does not appear on the THE list mainly because it was established in 1992 (University of Huddersfield n.d.), which makes it a novice university and thus cannot compete with the long history and relevance from the other universities on the top 100 list. However, two good reasons indicate that the high ranking for Huddersfield is appropriate. First the university is ranked among the 200 best young universities all over the world by THE. Second, Simon Iwnicki, the Head of Institute of Railway

Research at University of Huddersfield, is one of the most considered researcher in vehicle construction with his "Handbook of Railway Vehicle Dynamics" cited more than 650 times. The validation based on the THE ranking proofed as successful for this discipline, as well.

As already mentioned in the previous chapter the number of overall citations should not be chosen as the only criterion without any further detailed evaluation since departments or institutes at universities with more researchers in the rank of a professor are preferred to smaller research groups in this case. Figure 11 shows the average citations per university which is chosen as an additional criterion to validate the ranking of each individual university. Again, three of the five universities are also among the top five of the highest average citation count list. Milan Politechnico as well as TU Delft are no longer among the top five and switched to places 8 (Milan) and 10 (Delft). The reasons for this major change is that Milan Politechnico employees eight professors with railway safety focus who meet the criteria in this thesis. This is by far the highest number among the top ten universities and explains the lower average per researcher in comparison to the others. New in the top five are Heriott-Watt University and University of Sheffield, which are ranked sixth (Sheffield) and eleventh (Heriot-Watt) in the overall citation ranking. The reasons for the improvement of eight places from Heriot-Watt University is that only one single professor deals with mechanical engineering at this institution. This makes the University not that significant but since the overall citation count is equal to the average, the higher ranking is explainable.

Examining the positions of the three universities, which stay in the top five in both overall as well as average citation count, it is noticeable that Chalmers University of Technology kept its second place which verifies its importance in the mechanical Engineering area. Huddersfield improved to the top of the ranking mainly because of the reasons already explained in one of the previous paragraphs. There are three researchers from Huddersfield considered in the ranking. However, the number of citations by Simon Iwnicki exceeds the number of the two others multiple times. Therefore, the high influence of Simon Iwnicki and his top publications lead to the top ranking of University of Huddersfield. The improvement of University of Sheffield is only marginal since they are already ranked sixth in the overall ranking.

Investigating the distances between the universities in the average citation ranking it can be stated that compared to civil engineering as well as to the overall ranking in Figure 10

the ranking is less distinct. The first four places are among 20 citations difference which makes a clear placement difficult. Especially third place is shared between Sheffield and Heriot-Watt since the difference is only 0.5 citations. For a clear distinction between these universities other criteria have to be considered like the overall citation count or the THE ranking. However, a clear distinction between universities especially with these marginal difference is always a complex task since a lot of qualitative criteria should also be considered. In the end the rankings provide a tendency and clear statement such as: "This university is the third best in mechanical engineering" cannot be made. This tendency is sufficient for achieving the research objectives in this thesis. Therefore, the ranking has not to be analyzed in more detail.

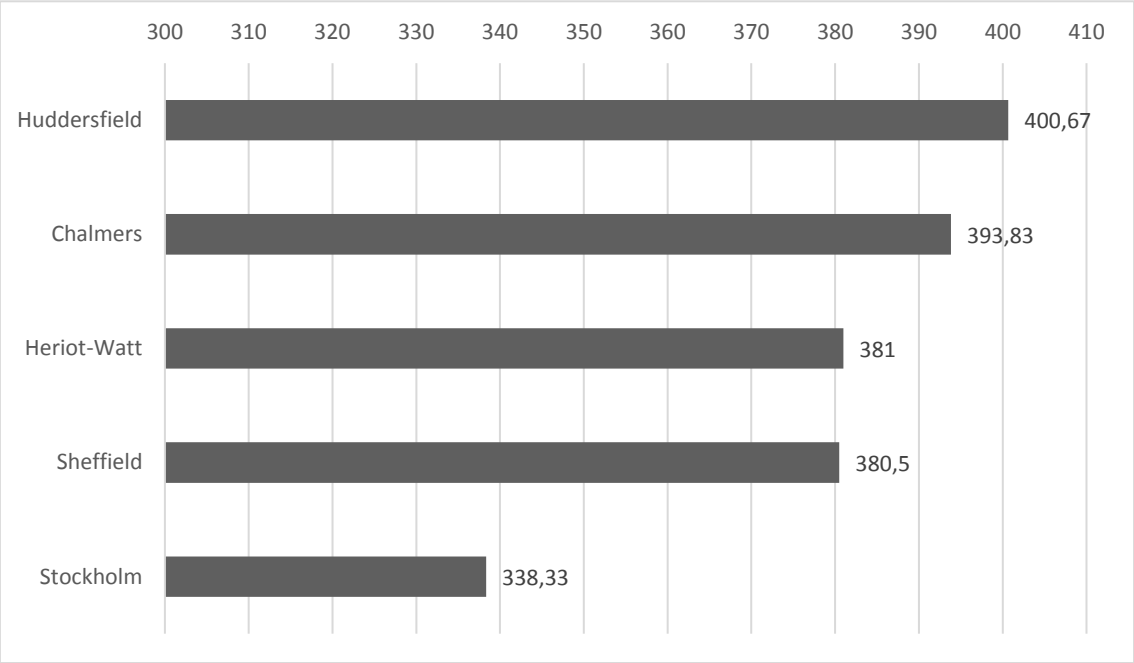

Figure 11: Top Five Mechanical Engineering Universities Based on Average Citations (Own Diagram)

Especially since the rest of the top ten universities are also ranked closely together, the sixth place University of Siena almost reaches the same average as the fifth place Stockholm. The same applies for rank 7 and 8 as well as 9 and 10. This observation shows that in mechanical engineering the universities are not that strictly separable by their quality in comparison to civil engineering. The reason for that could be multiple. Exemplary the citation behavior of researchers in the field could vary from other disciplines. Researchers could tend to prefer researchers with local proximity to their university which could lead to an equal distribution as observed in this section. Additionally, the specializations could be more distinct than in other disciplines which again could lead to having preferred universities for each specialization and consequently an equal distribution. These are only

explanatory approaches and have to be justified in a more detailed further analysis, which leaves room for future research.

Summarized the comparison of the overall citation ranking with the average citation ranking reveals that the overall citation ranking is a well-chosen indicator since the seven out of the top 10 appear in both rankings. Resumed the average citation ranking validates the overall citation ranking.

3.2.5 The Top Three Electrical Engineering Universities

The following section provides an overview of the top three electrical engineering universities in railway safety research. The basis for identifying these universities are again the overall and average citation count. In comparison to civil and mechanical engineering only three universities are introduced. This is because only five universities have been identified in total since the research field is not as broad spread as civil and mechanical engineering. It still makes sense to rank the researchers for two reasons. One is that the topics which comprise sensors, automatic train control and monitoring are highly relevant for the GRADE database and the research focus of the CCRDMT. The second is that in comparison to the three disciplines which are left out of the analysis in this chapter (safety engineering, computer science and biomechanics), the topic of electrical engineering is on the one hand historically anchored in railway research since the electrification of trains has started over 100 years ago. On the other hand, it is more diverse than the topics in the three excluded categories which all have a strict focus on a specific subtopic of railway safety research. The top three universities for electrical engineering based on the overall citation count are illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

In comparison to civil and mechanical engineering the distribution between countries is even more agglomerated. While the category of civil engineering is distributed over three continents, the mechanical engineering category still comprises four countries among the top five, while the universities identified in electrical engineering as top three are all originating from Great Britain.

In between these three universities the ranking is distinct. Loughborough achieved a clear first place. Salford and Birmingham are also clearly separated by more than 50 citations. The places 4 and 5 are in comparison irrelevant because their citation count is lower than 100. It would be interesting to discuss if the statements in this section on electrical engineering are as significant as in the two-previous sections since there are only seven re-

searchers considered in total. However, for the top three universities which have a significant citation count the results of the analysis should not be undervalued. For a future analysis, the data pool should be extended if it is possible to identify more universities matching the criteria.

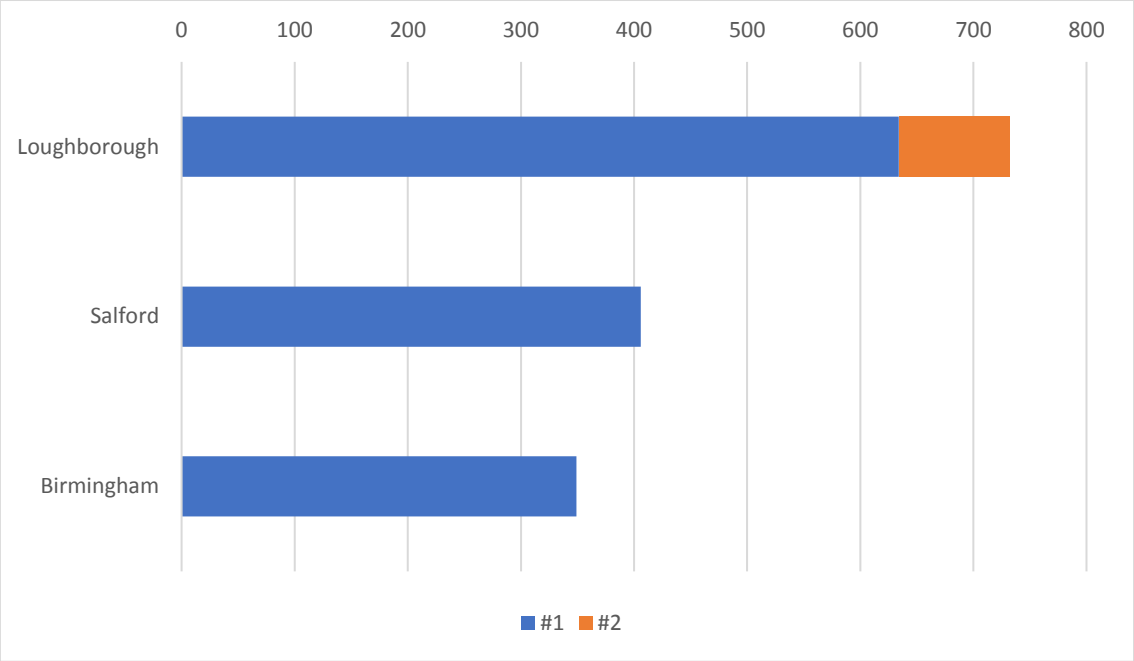

Figure 12: Three Overall Most Cited Electrical Engineering Universities (Own Diagram)

Following the relevance of the three identified universities is double-checked with the THE ranking. All three universities do not appear among the top 100 universities in engineering worldwide. On the hand, this could be an indicator for the fact that the ranking lacks significance. However, it is explainable for two reasons. One is that railway topics are of less significance in electrical engineering since they form specific subfield of the overall research field. Additionally, railway engineering as already outlined beforehand is historically located at mechanical engineering departments which leads to a higher influence in this discipline. The second reason concerns the three universities themselves. Loughborough as well as Salford are both young universities and appear among the top 200 (Salford) respective on rank 62 (Loughborough) in the young university ranking of THE. These places provide justification for ranking both universities on the top in electrical engineering since as already outlined previously it is more difficult for younger universities to achieve a top ranking because of their lower reputation. Birmingham on the other hand is one of the older universities and it also appears on place 130 of the THE ranking, which is still a good position considering the high quality among the top 100. Concluding it can be stated that the verification of the results based on the THE ranking

is not as successful as in the other two disciplines. However, this could be caused by the small number of included universities.

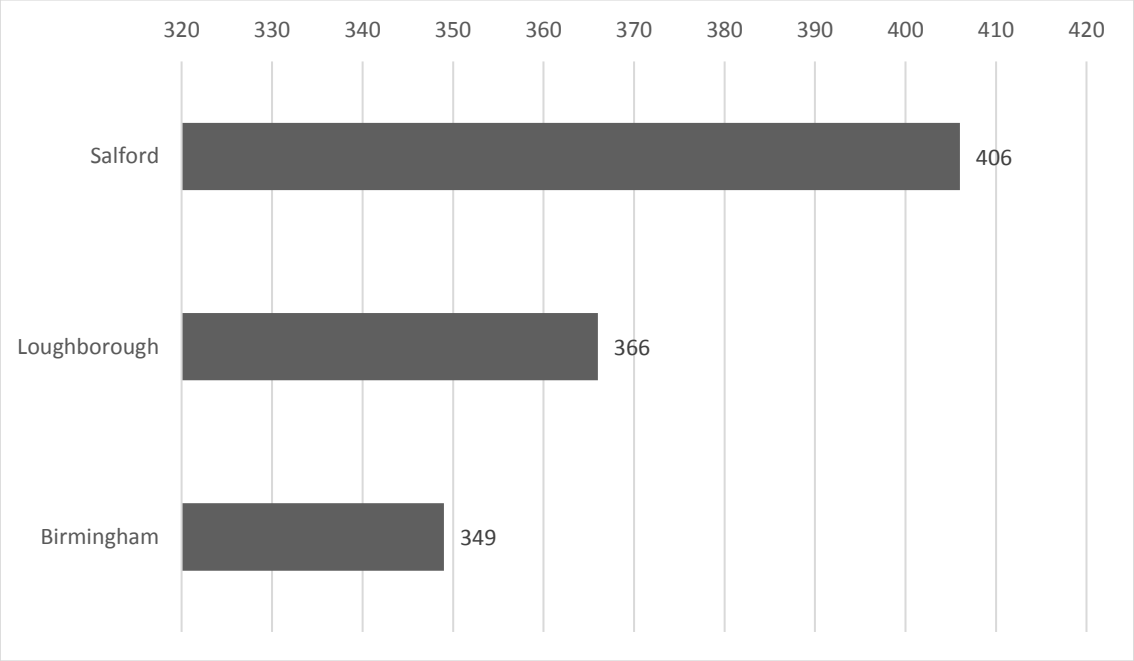

Figure 13: Top Three Electrical Engineering Universities Based on Average Citations (Own Diagram)

In the following the results of the overall citation count are compared to the average citation count per university in Figure 13. Salford and Loughborough have switched places in the average ranking while Birmingham keeps the third place. This is because Loughborough has two researchers who meet the criteria and therefore its average count is divided by two which is not the case for the Birmingham and Salford which only have one researcher. The places 4 and 5 are also matching with the overall ranking. Since the size of the sample is very small for electrical engineering, the opportunities for interpretation and comparison of both rankings are also minor. Still places 4 and 5 are of low significance because of their small citation counts. For the first three places the distances are still distinct with Salford in clear first position. However, second and third place are closer together with a difference of only 17 citations. Additionally, it can be stated that besides the changes on the top position, the average citation ranking confirms the overall citation ranking, although the conformation itself is not that significant since the probability for changes in ranking is relative low because of the small sample size.

3.2.6 Overall Implications from the Ranking in the Three Categories

In the previous three sections the most relevant universities based on the citation counts are determined. The ranking of the universities is divided by the discipline in which they

conduct their research as a category. For each of the three categories which are investigated the top three respectively the top five universities are determined. For mechanical as well as civil engineering, the ranking procedure is significant which is proven by double checking the results with the THE ranking as well as checking the overall citations per university with the average citations. For both disciplines this double-checking procedure proofs to be successful since it validates the results of the overall citation count ranking. Since the sample size for both disciplines is around 30 universities, the results are significant. For electrical engineering the judgement varies since the sample size is relatively small with five universities and the confirmation with the external variable from THE is not that distinct. This leaves open rooms for further research on an appropriate ranking procedure in this category.

Concluding this chapter, another peculiarity should be mentioned. As already pointed out beforehand out of the 59 universities which are included in the analysis in total, 13 are conducting railway research in different disciplines. First, this shows that these universities have a strong focus on railway research since multiple departments contribute to the research field. Second, this makes it possible to conduct multi-disciplinary and therefore probably more valuable research in comparison to universities with a single research focus.

Two of these multi-disciplinary universities are presented here in more detail since they achieved high rankings in two disciplines which increases their overall significance. The University of Birmingham with its Birmingham Centre for Railway Research and Education is one of the most important railway research institutions with over 130 researchers and several important industry collaborations. Therefore, it is not surprising to find this university ranked sixth in civil and third in electrical engineering. The second considered university is Heriott-Watt University which achieves rank 8 in civil and rank 11 in mechanical engineering. This is because the Institute of Energy, Geoscience, Infrastructure and Society are considered experts in track development with major testing facilities for examining the durability of railway track. Most of their expertise is therefore in civil engineering, however one of their researchers is also an expert on the wheel-rail interface which is an interdisciplinary topic between mechanical and civil engineering. This makes their research influential in both areas.

In this chapter universities and their respective researchers are ranked based on their publications. This ranking procedure proofed successful also after validation with an external

variable. Therefore, the data pool collected for this analysis should be utilized in more detail by conducting a topic analysis in Chapter 4.

4 Publication Analysis for the Identification of Relevant Research Topics

In this chapter the most investigated research topics for railway safety research are identified. Therefore, at first a method is developed which should enable to identify these topics. After that the method is applied on the identified literature from the researcher introduced in the previous chapter.

4.1 Method for Identifying the Most Relevant Research Topics

There are several ways for the most relevant and investigated research topics in a research field. The article by LaPlaca (2013) is taken as a guideline, not because of the research topic which is business-to-business (B2B) marketing and therefore far away from railway research, but because the pool of methods for identifying relevant topics is diverse. LaPlaca proposes three methods of identification.

First, suggestions from well-known subordinate research institutes are stated. In marketing science, a "Marketing Science Institute" exists, which has the standing as well as the reputation to come up with the top research priorities every two years. The standing of this institute is based on their well-known members which consists of the top US companies like McDonalds, Facebook, Pepsi, etc. (Marketing Science Institute n.d.). Therefore, their suggestions for research topics is highly valued. In the railway sector, mainly two players could come into questions which have a sufficient standing to provide advice of the same kind of quality. The UIC with its associated IRRB includes 197 railway and railway infrastructure companies all over the world and therefore is predestinated for providing advice on future research topics. With the IRRB they already established an institution which should coordinate company-internal research in between these companies to foster synergies between different countries around the world. At the moment, this institution however does not provide these suggestions for university researchers. Therefore, their guidance cannot be used as basis for this thesis.

The European Railway Research and Advisory Council (ERRAC) follows the same ideas as IRRB, however their activities for the last two years have not been updated on their website (European Railway Research and Advisory Council n.d.). This institution provided research priorities in a noteworthy report stating research priorities until the year 2020, which is however outdated since it is 10 years old (European Railway Research and Advisory Council 2007). However, this report was updated in 2014 now aiming at research and innovation in railway until 2050 (European Railway Research and Advisory

Council 2014). ERRAC is closely linked to the Union des Industries Ferroviaires Européennes (UNIFE).

UNIFE is the second player with a sufficient standing in the railway sector which could specify the railway research priorities. UNIFE is the biggest branch association from the railway supplying industry which comprises all mayor players from the European market like Siemens, Voestalpine, Alstom, etc.(Union des Industries Ferroviaires Européennes n.d.). Their standing in the railway sector can be demonstrated by two numbers. All members of UNIFE together have a market share of 46% on the worldwide and 84% on the European railway market (Union des Industries Ferroviaires Européennes n.d.). UNIFE as an organization is not only part of participating in ERRAC but also in several EU funded projects like Horizon 2020 or Shift2Rail. Their research activities however do not include providing guidance on future research topics for universities. Therefore, their expertise and guidance cannot be utilized for this thesis. Nevertheless, these two players are potential candidates for taking over this task.

Second, LaPlaca suggests interviews among experts as an appropriate measure for identifying research priorities. These interviews can be performed on two target groups. The first are experts from the industry. Therefore, organizations like UNIFE are predestinated because their board consists of the highly influential employees from the most important players on the railway supplier market. The second are experts from research, which could be identified by looking for example at the reviewers of important journals or the advisory committees from significant conferences like WCRR. This approach could also be applied in this thesis, but it is not used for two reasons. First, preparing, conducting and evaluating these interviews would exceed the scope of this thesis in terms of time as well as content. Second, the establishment of connections to all these researchers would be difficult. This approach could be performed later to validate the results of the analysis in this chapter as well as the identification of the top researchers and universities in Chapter 3.

The third method would be investigating the call for papers from major journals and conference in railway research. This method is well-fitting for disciplines like B2B marketing in which two to three major journals are the leading forms of publication and are accepted by the research community. As already explained previously this does not apply for the railway safety research field since it comprises researchers from multiple research fields and therefore also different leading journals and conferences. This prevents an overall

identification of research priorities by these methods. However, for the sub disciplines like civil engineering this approach could be applied. Nevertheless, the approach is not used in this thesis for two reasons. First it is questionable if the research area of railway safety research can be fully covered by this approach. This is because selecting distinct journals with high significance in the individual disciplines bears the risk, that specific research areas are preferred over others since the journals of the respective research area are higher ranked in comparison. This could lead to an undervaluation of topics which are nevertheless important in railway safety research. Consequently, this problem is also caused by the multidisciplinary composition of railway safety research. Second, the approach is time-consuming and would require a longer phase of investigation to first get familiar with the different subtopics and then identify the most important forms of publications in each of them. Additionally, interviews among experts could be necessary to validate the identified forms of publications.

Since all these approaches have not proven applicable for the reasons mentioned in the previous paragraphs, a new approach is developed which fits the needs of this thesis. Nowadays it is usual to use keywords to structure content on the internet or even on the private PC. In this context, mainly two systems are common. The first is tagging which is broadly used on the web to describe content of any kind. Through tagging folksonomies are created which are keyword collections and are created by the users of certain platforms or software. On the other hand, there are taxonomies. Still the goal is to describe for example publications by relevant keywords. However, the set of vocabulary is controlled by a subordinate organization to ensure a structured approach. Both methods have their advantages and disadvantages. Taxonomies avoid chaos, folksonomies enable creativity. In this thesis, those keywords which are assigned by the authors to their articles are analyzed to identify the most investigated topics. This method could be a well-fitting approach to understand which research topics are already in the focus of researchers and which should be more focused in the future. The problem during the agglomeration process of the keywords is that not all articles which are identified in Chapter 3 are assigned with keywords. In this case the titles of the articles are used and all nouns with their corresponding adjuncts are transformed into keywords. This approach is used since the author lacks expertise in railway engineering and therefore an identification by reading or scanning the publications will not always be successful. Since the basis for including publications in the analysis in Chapter 3 is that the articles have to be among the top five cited of each researcher which should indicate the relevance. Therefore, the keywords

included in this analysis should be both relevant as well as significant because they meet the selection criteria applied in Chapter 3. These keywords are collected in one text file and then analyzed via a word cloud[17]-generator[18]. Since the generator only counts single words combinations of more than one word are connected by a hyphen.

4.2 Application of the Method on the Selected Publications

In this section the method which is described in section 4.1 is applied to all publications which are identified in Chapter 3. Since the applicability of this method is based on enough data, the method is only applied on the two categories civil and mechanical engineering. These categories comprise enough researchers, 64 for civil engineering and 61 for civil engineering, which leads with five publications per researcher to a fitting number of keywords. In electrical engineering that is not the case and therefore the method cannot be applied. This section is separated into three parts consisting of observations during the collection process being described followed by the results for each of the two disciplines being analyzed in separate sections.

4.2.1 Observations during the Agglomeration Process

During the agglomeration process of the keywords differences between the disciplines are observed. In mechanical engineering, more articles are tagged with keywords. Around 70% could be taken over from the publications. In civil engineering the quota is worse with 50% of the articles with assigned keywords. Therefore, in the cases, in which no keywords were assigned, they are created from the publication title. The difference in the frequency of articles assigned with keywords between civil engineering and mechanical engineering can be explained by several reasons which not necessarily have to relate to the discipline itself. Some publishers, for example, require the authors which want to publish in their journals to assign keywords when they hand in the article, which results in the fact that all articles published in these journals are assigned with relevant tags. Second, tagging with keywords is phenomenon which experienced a major growth through the rise of the internet. Therefore, articles published in the recent ten to fifteen years have a higher probability to be tagged. Third, it not only depends on the publishers if keywords are assigned mandatory or voluntarily, it also depends on the publication

[17] Word clouds or tag clouds are a visualization of rich text information, in which the frequency and consequential the prominence of each word is indicated by its color and font size. The basis for determining the font size as well as the color is a weighting algorithm.

[18] See: www.wortwolken.com

type. It is not common, for example, to tag books since their width of content can make it difficult to find specific keywords like they are assigned to articles. These are only basic approaches for explaining this peculiarity. However, it is not the topic of this section to understand why keywords are used and why they are not.

The approach of identifying the most relevant topics in each discipline by analyzing the keywords is performed via two formats of visualization. First the keywords are listed in a table with their individual keyword count. Out of this table a word cloud is created which visualizes the most frequently mentioned keywords and thus displays the results in a more appealing and processible way.

4.2.2 Keyword Analysis for Civil Engineering

In Table 7 the most mentioned keywords for civil engineering are listed and additionally, they are also visualized as a word cloud in Figure 14. For simplifying the interpretation generic keywords are, although they are part of table, excluded from the analysis. Also, all words which are mentioned less than three times are not part of the table since they lack significance as part of 1062 keywords. The keywords which are excluded from the interpretation are not printed bold. Looking at these excluded words two categories can be identified. One is the part of the railway system which is analyzed. They are marked with a superscript one. These keywords can be of relevance in a more detailed analysis; but, as they are listed here out of context of the actual publication, the interpretation is not possible. The second kind of excluded keywords are the scientific methods which are applied in the respective article. These could be interesting if the research interest was on the concepts which researchers frequently use, however this is not topic of this thesis. These concepts are marked with a superscript two. After having excluded these keywords six keywords are still on the list, however high-speed and high-speed train can be brought together to one category.

Table 7: Most Mentioned Keywords for Civil Engineering (Own Table)

Keyword	**Count**
way[1]	10
genetic-algorithm[2]	7
maintenance	7

way-infrastructure[1]	6
high-speed-train	6
high-speed	6
way-bridge[1]	6
way-track[1]	6
road[1]	6
way-wheel[1]	5
vibration	5
ballast[1]	5
track[1]	5
experimental-validation[2]	4
numerical-modelling[2]	4
dynamic-analysis[2]	4
kalman-filter[2]	4
fatigue	4
safety	4
wheel[1]	4

This keyword category also has the highest rate of mentions, which indicates that the changing process from common trains to more high speed tracks seems to influence not only the railway companies but also the research which has to come up with solutions for problems caused by these higher speed levels. The track is stressed with much higher impact levels and therefore the civil engineers have to test and develop new or improved materials for ensuring that the track can sustain this stress.

The second keyword on the list which is mentioned seven times in total is maintenance. The reasons are based on the current developments in the railway sector. As already explained in most railway networks, such as in Germany, the frequency of traffic is increasing especially through the increasing number of passengers. Therefore, the track wears out faster and has to be maintained more frequently. Researchers have to come up with

solutions for improving this maintenance process especially since blocking the track for a long time is economically harmful for the railway company. Closely related to maintenance as a topic is fatigue which is mentioned four times. This is because material fatigue is one of the main reasons for maintenance of track. Again, the high workload track is exposed to exacerbate the material fatigue which is already influenced through environmental effects like temperature, rain or insolation. Therefore, developing new measures and materials which contain or slow down the fatigue process is necessary.

Figure 14: Most Mentioned Keywords for Civil Engineering Word Cloud (Own Diagram)

Additionally, vibration is also mentioned five times. Vibration as well as noise analysis of railway vehicles in interface with the railway track is a separate research topic in civil engineering but has direct relation to mechanical engineering, as well. The relevance of this topic is justified through its variety of potential applications. Vibrations, for example, can indicate wheel flats which are both an accident risk as well as a damaging factor for the railway track. Also, they can gradually damage trackbed and the underlying soil which in the end leads to severe movement of the track.

The last keyword which is also mentioned four times is safety. Railway safety it is the topic of this thesis and the relevance of the topic is explained in Chapter 2. For establishing further contacts to other universities, the CCRDMT should utilize his information and identify the university with a clear safety focus.

These five overarching keyword categories form the core of research topics for civil engineering research. This basic identification can be used for multiple purposes. Experts can be interviewed to identify gaps in the research which are not covered by these subordinate categories. Furthermore, the categories could be analyzed more closely by dividing them into subcategories. For these purposes the keyword identification provides a solid basis.

4.2.3 Keyword Analysis for Mechanical Engineering

In this section the same approach as in section 4.2.2 is applied. Table 8 illustrates the keyword list arranged in descending order by the count of each keyword. Again, keywords have to be excluded from the analysis because they lack meaning or are not significant for the analysis. Additionally, all words which are mentioned three times or less are excluded – they lack relevance as a part of 909 analyzed keywords. In the table the excluded keywords are not printed bold. Among these excluded keywords three categories can be identified. They are again marked with a superscript. Two categories are identical to the section 4.2.2. Again, marked with superscript one, keywords which describe the unit of analysis of the railway system are highlighted. With superscript two the applied methods are emphasized. The reasons for excluding both categories are explained in 4.2.2. Third, keywords which lack context or are too generic are excluded as well. In total nine keywords remain on the list. However, “railway dynamic” and “vehicle dynamic” are highly similar and therefore could be condensed into one keyword. For a quick overview of the keyword list a word cloud is provided in Figure 15.

Table 8: Most Mentioned Keywords for Mechanical Engineering (Own Table)

Keyword	**Count**
rail-vehicle[1]	12
wheel–rail-contact[1]	8
rail-corrugation	8
vehicle-dynamic	8
railway[1]	8
condition-monitoring	7
railway dynamic	7

squat	7
rail[1]	7
wind-tunnel-test[2]	6
wheel[1]	6
numerical-simulation[2]	5
railway-vehicle[1]	5
railway-track[1]	5
experimental[3]	5
aerodynamic-coefficient	4
rolling-contact-fatigue	4
dynamic-interaction[2]	4
multibody-dynamic[2]	4
independent-wheel[1]	4
high-speed-train	4
numerical-model[2]	4
railway-bridge[1]	4
simulation[2]	4
dynamic[3]	4
wear	4

The combination of these two keywords leads to the most mentioned category with 15 mentions overall. The reasons for this are among others the deep roots of the topic in mechanical as well as vehicle engineering. It is not only a topic of railway research but it concerns vehicles for all modes of transportation. Investigating the dynamic behavior of a vehicle during travel is basic for ensuring a safe and efficient travel. Especially with the increasing level of travel speed through high-speed trains research has to adapt to these challenges of the changing vehicle dynamics.

Second, rail corrugation as well as rail squats are mentioned eight respectively seven times. Both topics are induced by vehicles which are wearing out the rails through the

continuous forces they are conveying to the rails. These phenomena are both negatively influenced by the increasing speed of railway vehicles as well as deficient maintenance of wheels. Therefore, they are directly linked to improved maintenance procedures as well as better materials.

Another topic which is mentioned seven times is condition monitoring which is also a research field of the CCRDMT. Therefore, research in this topic is relevant for the different projects in the CCRDMT. Starting in the 1940s the change from manual inspections to automatic sensor technologies was and is highly influential on railway research as well as the railway industry. Even today this change is still in progress since new sensor technologies and Internet of Things (IoT) devices are included in more and more parts of the railway vehicles. In the long run this will both lead to improvement in maintenance procedures as well as safety of railway traffic. Therefore, researchers are and should be dealing with this topic in the future since it is of high practical relevance.

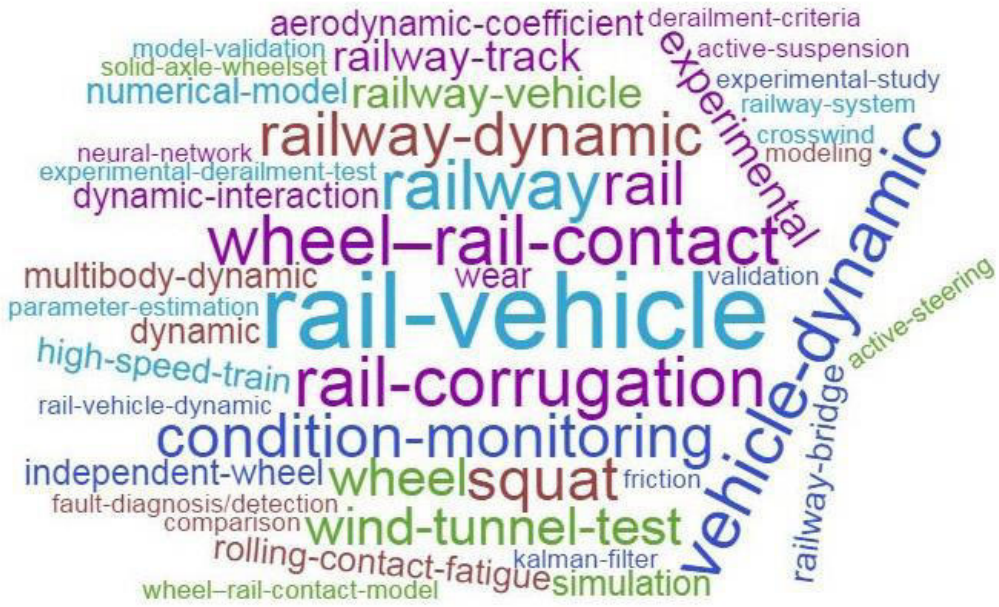

Figure 15: Most Mentioned Keywords for Mechanical Engineering Word Cloud (Own Diagram)

In the list of keywords which are mentioned four times the two keywords, fatigue and high-speed train, are already explained and analyzed in section 4.2.2 on civil engineering. This shows the high interference of both disciplines which is necessary to ensure effective research since the infrastructure should never be examined separately from the rolling stock and vice-versa. Both the rolling-contact fatigue, which describes the influence of

the rolling stock on the material fatigue of rails as well as the high-speed trains are also major topics in mechanical engineering. Furthermore, wear is also a general topic of both disciplines which is closely linked to fatigue as well as maintenance.

The last keyword which is also mentioned four times is “aerodynamic coefficient”. Railway aerodynamics is a large research field which is part of mechanical engineering, as well. Especially at Milan Politechnico several researchers deal with this topic. Its high relevance stands to reason since the increasing speeds of railways require improved aerodynamics to ensure an efficient and safe travel with high-speed railway.

Overall these keywords show the broad spectrum of mechanical engineering which starts with dynamics of vehicles, is followed by modern sensor technologies, which enable and facilitate condition monitoring, and ends with railway aerodynamics. All these are related but also highly diverse research fields. Especially for identifying gaps in mechanical engineering research as well as finding potential interfaces or synergies between the topics this basic analysis can be utilized. A more detailed reflection of the individual research topics which relate to the keywords can lead to an overview which can be exploited for creating for example relevance trees for each of the subcategories.

5 Conclusion and Outlook

In this chapter, a conclusion and an outlook for the thesis are provided. The conclusion is guided by the research questions which should be answered by now. The status of each research questions is discussed in more detail in the first section. Furthermore, the implications of the thesis for the CCRDMT are discussed. The second section discusses future research which can be build up on this thesis. Therefore, it picks up on hints which have already been raised throughout the previous chapters.

5.1 Conclusion

Before answering the research questions, the thesis had to be build up on a solid scientific foundation. Therefore, the method chosen for identifying researchers and universities with high influence on the research field of railway research was the literature review. It is the most suitable method for this task since the goal of a classical literature review is identifying the most influential articles on a field while providing an overview of the subfields as well. Since the most relevant articles are usually published by the most influential researchers, the approach is standing to reason. For developing a better understanding of how to conduct a literature review the work of important scholars in the field research methods such as Creswell was consulted. Based on this work helpful hints on how to select the relevant literature have been adopted. The publication type, the number of citations as well as the date of the publication were also applied for selecting the relevant articles in this thesis. Furthermore, it is recommended by several scholars to use a literature search engine like Google Scholar for identification and a reference management systems for maintaining order. These hints were both applied in this thesis. Additionally, it is also recommended to set a clear timespan for the reviewing process because the method bears the danger to get lost in an overload of information. Therefore, the search in this thesis was stopped as soon as the same researchers and universities came up again and again. These were the main outcomes of Chapter 2. Chapter 3 started to answer the research questions. For simplification reasons the research questions are repeated in this section.

RQ1: Who are the most influential researchers and universities in their respective area of railway safety research?

For identifying these researchers, a structured approach had to be developed. At first the sources of identification had to be determined. Mainly six sources were used for this thesis: a list by a former CCRDMT student assistant, Google search, websites of subordinate

research organizations, websites of already identified universities, Google Scholar and the SPARK database. After this agglomeration process selection criteria had to be defined to ensure that only relevant universities and researchers are included in the analysis. Therefore, the list of universities was checked against five criteria: relation to the research topic in terms of safety, academic rank of researcher, publication language, publication quality and number of citation. Out of the 105 listed universities 59 fulfilled all five criteria. Before these 59 universities and their respective researchers could be ranked, they had to be categorized first since comparing researchers from completely different disciplines does not make sense. Out of these 59 universities six categories could be identified which are identical to the disciplines. The categorization process is described in RQ3. For ranking the universities, a measurable criterion had to be defined. Since quality and relevance of researchers are complex constructs which consist of several variables (industry cooperation, teaching, international orientation, experience in research funding, etc.), the complexity had to be broken down for reducing the time required for conducting the ranking procedure. Therefore, the number of citations as a measurable criterion for each researcher of each university was taken as an indicator for the relevance of the respective university. To validate this criterion the THE ranking was chosen as an external variable to ensure that the ranking is significant.

Out of this criterion a ranking for the three disciplines electrical, civil and mechanical engineering was developed. The other disciplines were excluded since the number of universities was too small to ensure significance of the results. For civil engineering, especially the universities of Leuven, Wollongong and Southampton could be identified as the top three contributors in their discipline. This ranking was based on the overall citations which is the sum of the top five articles of each professor at the respective university. To ensure validity of the data it was not only checked against the THE ranking but also against the average citations per researcher to make sure that larger universities are not benefited. Based on both validity checks the ranking could be identified as significant. The top researchers for civil engineering are also member of these top three universities: Geert Degrande, Buddhima Indraratna and David Thompson.

For mechanical engineering, the same analysis was conducted. Again, the validation of the data against the average citations as well as THE ranking was successful. So, the ranking results are significant. The top universities based on overall citations in mechanical engineering are Milan Politechnico, Chalmers University of Technology and the Royal Institute of Technology in Stockholm. Out of the top three researchers only two

are member of these universities. Simon Iwnicki, the top cited researcher in mechanical engineering, is member of the University of Huddersfield, which achieved rank four in the overall ranking. On rank two and three Jens Nielsen and Anders Ekberg from Chalmers University of Technology follow up.

In electrical engineering the ranking procedure was based on only five identified universities. Therefore, the significance of the ranking can be questioned. Additionally, in comparison to the other disciplines the validation against the THE ranking was less definite. However, the identification of the top three of out these five universities was distinct. It was Noticeable that these three are in Great Britain with Loughborough achieving first place, Salford second and Birmingham third. The top three researchers are also member of these universities: Roger Goodall, TX Mei and Clive Roberts.

With these top researchers and university, a method had to be developed to identify the most relevant and investigated research topics in each of these research categories. How this was achieved is described in the next paragraph.

RQ2: What are the most relevant topics in railway safety research?

For identifying the relevance and significance of topics in a specific research area, several methods are recommended by scholarly literature. Expert interviews, research priorities from research organizations and call for papers from relevant journals and conferences all proved inappropriate for being applied in this thesis for several reasons. Therefore, a new method had to be developed. Nowadays it is common to tag scientific work with keywords describing the publication for purposes of categorization. Since the most relevant articles for each discipline have been identified for answering the previous research questions, the keywords which come along with these articles can be utilized. Their frequency is evaluated and they are ordered in tabular format. This procedure was applied on civil and mechanical engineering since enough keywords are available for both. Thus, intersections between both disciplines have been identified. Especially the area of maintenance as well as high speed trains are influential research topics for both disciplines. Furthermore, focus points for both disciplines have been identified like railway dynamics or condition monitoring (mechanical engineering) and material fatigue or railway-induced vibrations (civil engineering). Out of these results synergies between different research areas and disciplines can be identified as well as research gaps which can be closed with future research.

RQ3: How can railway safety research be categorized?

By answering the previous research questions, it was pointed out that a categorization scheme was applied to structure the identified universities and researchers. This was necessary to ensure comparability between the units of analysis. The main difficulty in implementing such a categorization scheme for the topic of railway safety research is its diversity. However, applying a scheme which tries to depict this diversity fully bears the risk to get lost in details. To avoid this a high-level scheme was established which can be refined in future research. This scheme adopts the research discipline of each researcher as a category. One advantage of this approach is that the discipline can be clearly determined. Furthermore, it can be guaranteed that the researchers are comparable among each discipline since they have developed common traditions throughout their historic development.

RQ4: How can relevant topics in railway safety research be identified?

As already explained while dealing with research questions several reasons were indicative that the keyword analysis is the right method for this thesis. First, expert interviews were not suitable since the identification of and contact establishment for suitable experts would be too time-consuming and difficult. Second, subordinate research organizations which provide lists of relevant topics for railway research do no exists in the same way it is common for other disciplines. For railway research organizations like the IRRB exists. However, they do not provide any kind of suggestions for future research. Third, call for papers of relevant conferences in the field could be scanned for identification of the topics. However, the problem is the diversity of the field which makes it difficult to find conferences which cover the whole research field of railway safety. Therefore, if this method would have been applied, it would be difficult to ensure not leaving out important areas of the whole research field. Nevertheless, it can be an approach for future research. Due to all these exclusion criteria, a new method was developed. The keyword analysis is an approach which fits the goals of this thesis. Since a generic overview of the research topics for each of the categories should be provided, keywords are by their nature an appropriate means. As it is common nowadays to tag publications, the data pool is also comprehensive enough. On this pool of data the word count of each keyword is calculated. To ensure significance a minimum number of mentions is required. Additionally, keywords which are too generic do not contribute to the analysis because of their lacking context are excluded. For a better visualization, a word cloud is added for each of the disciplines.

These are the results for each of the research questions. Equally important as pointed out in the motivation is the relevance of this research for the CCRDMT. Therefore, implications for the CCRDMT are summarized in the following paragraphs.

In Chapter 3 subordinate research organizations like the IRRB are introduced. For the CCRDMT it could also be beneficial to become a member of one of these organizations. A membership could be useful for networking purposes, applying for funding in bigger projects which are advertised to broader research or for utilizing synergies in research between universities.

Furthermore, the experts and universities which are identified in Chapter 3 can be contacted for potential partnerships as well as their expertise in their specific field. Since the CCRDMT lacks engineering expertise such a partnership could be promising, especially for the GRADE database. Complementary the information extracted from the keywords could be related to the accident causes in the database. GRADE provides a detailed overview of more than 40,000 railway accidents. With statistical analysis problem areas in the railway system can be identified. For example accident causes could occur which are responsible for a relative majority of the damages and accident costs. These causes should be related to the identified research topics. If they are not represented in the current research accordingly, a research gap is identified, whose necessity can be justified through the economic benefit. This correlation of research topics with accident causes could form a basis for a future research project.

Overall, it can be concluded that the CCRDMT research – examining the railway industry from an economic as well as organizational perspective – is not reflected in the identified universities as well as researchers. This research still plays a minor role in the railway research community. This is a chance as well as a challenge for the CCRDMT. Being perceived in the scientific community is more difficult since the leading researchers come from engineering institutions. However, the relevance of IT in the railway sector is increasing as it is in every industry. Furthermore, the economic pressure on railway in comparison to other modes of transports is also growing. These arguments are a chance for the CCRDMT with its unique research focus to fill more research gaps in the future with its interdisciplinary research.

5.2 Outlook

In several sections of this thesis potential for further and more detailed research was indicated. The following section provides an overview of all these indications as well as summary of opportunities for future research.

Directly building up on this thesis should be the validation of the results. As already outlined beforehand expert interviews are a suitable measure to identify relevant universities and topics. Therefore, it can be recommended to build up on this work here and verify the results with an expert questionnaire. This would increase the validity by including another valuable external variable besides the THE ranking.

A considerable pool of 105 universities was agglomerated in this thesis. However, the overall research field is much bigger, especially when considering that all railway research topics which are not related to railway safety were excluded from the analysis. Therefore, a broader spectrum of universities as well as researchers should be included in the analysis to fully depict the spectrum of railway research. For doing so new methods of identification must be applied, for example the THE ranking of the best engineering universities which in this thesis was used for validation purposes could be scanned for more universities with railway focus. Additionally, a search in relevant engineering journals for railway topics could be helpful for identifying more researchers and therefore universities. These journals could be identified by journal ranking for engineering which are available on the Internet. Using ranking would also ensure the sufficient quality of the publications.

The topic of the last paragraph was broadening the research of this thesis. However, there are also possibilities for deepening it based on the data which is already gathered. At the moment, the data is collected in Excel, but for future analysis, especially regarding statistical as well as data analysis, a more powerful tool like IBM SPSS should be used for identifying correlations, clusters or relevant factors between the identified variables. Especially the keyword analysis bears the potential for identifying correlations such as between the research topic and the year of publication which could be created to show the development of a specific topic throughout the years. Furthermore, the applied categorization is not detailed. However, if the number of universities and researchers is increased, the number of categories for each discipline could also be increased and still the relevance of each category could be ensured. This would offer the opportunity to provide an in-

depth overview of all the subtopics in each discipline and therefore develop a more detailed understanding of the relevance of each of these. This could be very helpful for understanding and identifying even more research gaps and synergies.

In the analysis in Chapter 3 the ranking procedure for the universities and researchers is based on the number of citations as the only criterion. However, the relevance and quality of a researcher and university depend on several more, mainly qualitative criteria. For a future and deeper analysis, these criteria should be considered as well, for instance, the number of students which achieve their degree in the respective discipline of the researchers could be a criterion of relevance. Furthermore, the quality of the teaching which is for example evaluated by questionnaires among students should be considered because it is an indicator of a good scholar. Since railway research is an applied science the size of external funding from industry or state funds should also be considered to rank universities and researchers. The difficulty in considering all these criteria is that it is more complex to obtain the relevant information as well as to develop an appropriate measurement scale. However, it would increase the representativeness of the ranking. Therefore, the effort should not be shied.

Since already a profound number of relevant publications has been identified in this thesis, this data could be utilized in more depth. These publications are linked to the journal, conference or book, they are published in. Especially for journals and conferences it is common to rank them via their impact factor. However, this procedure is applied per discipline and not cross-disciplinary as the literature review is conducted in this thesis. Therefore, a cross-disciplinary overview of the most relevant publication formats could be developed out of data collected in this thesis.

As already explained in Chapter 4, the keyword analysis for identifying the relevant topics in railway research is highly suitable for this thesis. However, this form of analysis lacks depth since it collects merely quantitative data. Qualitative approaches like experts interviews as well as collecting the call for papers of relevant formats of publications should be considered as well for future research although they can be very time consuming. This would not only be necessary for validation purposes of this thesis, but also for broadening the data basis as well as deepening the degree of detail.

In one of the previous paragraphs it was recommended to use IBM SPSS or a comparable tool for deepening the analysis. What could be of special interest in doing so are the connections between authors and their co-authors as well as how researchers change their

universities to reveal connections between different universities. This is important for two reasons. If researchers cooperate with co-authors from other universities, this shows the international orientation – if the other university is in a different country – as well as a potential partnership between universities which would also increase the influence of the individual university. Furthermore, it is also an indicator of quality of researchers who do not publish constantly with researchers from the same university. This is because it shows that the researchers are willing to occupy a broader perspective.

As a final implication, the cooperation of universities and researchers with industry partners should be investigated as well. This is relevant for two reasons. First, it shows the relevance of the researcher or university because industry collaboration is a quality indicator for an applied science like railway research. Moreover, it also illustrates which companies are especially active in funding as well as cooperating with universities. Therefore, also a relevance ranking for the railway companies regarding their support of research could be conducted. This would show which companies invest the most in railway research and furthermore correlations between the locations of the universities and the companies could be established. Although this information is hard to obtain, the effort should not be shied since it could also be relevant for the CCRDMT for identifying potential new industry partners.

Concluding, it can be stated that the research questions could be answered to a satisfactory extent, which is an indicator of success for this thesis. The ranking procedure for researchers as well as universities was successful and could be validated. For the identification of relevant and current topics an exploratory method was applied, which should be tested and utilized in more detail in the future. The great extent of implication for future research in section 5.2 shows that the research conducted in this thesis will be fruitful for more research in the same or similar areas.

6 Bibliography

Arai, M., 2003. Railway safety for the 21st century. *Jpn. Railway Transp. Rev*, 36, pp.42–47.

Booth, A., Sutton, A. & Papaioannou, D., 2012. *Systematic approaches to a successful literature review*, Sage.

Cooper, H.M., 1998. *Synthesizing research: A guide for literature reviews*, Sage.

Coursen, S., 2010. Safety vs. Security: Understanding the Difference May Soon Save Lives. *Safetymadesimple*. Available at: https://safetymadesimple.wordpress.com/2014/08/31/understanding-the-difference-may-soon-save-lives-safety-vs-security-spencer-coursen/ [Accessed May 17, 2017].

CRC for Rail Innovation, CRC for Rail Innovation. Available at: http://www.railcrc.net.au/about-us [Accessed June 13, 2017].

Creswell, J.W., 2013. *Research design: Qualitative, quantitative, and mixed methods approaches*, Sage publications.

Department of Industry Innovation and Society, Cooperative Research Centers Programme. Available at: https://industry.gov.au/industry/IndustryInitiatives/IndustryResearchCollaboration/CRC/Pages/default.aspx [Accessed June 13, 2017].

Deutsche Bahn, 2017. *Anzahl der Reisenden im Schienenpersonenverkehr der Deutsche Bahn AG in den Jahren 2005 bis 2016 (in Millionen)*, Berlin. Available at: https://de.statista.com/statistik/daten/studie/13626/umfrage/reisende-im-schienenpersonenverkehr-der-db-ag/.

Edwards, C., 1997. Railway safety cases. In *Safety and Reliability of Software Based Systems*. Springer, pp. 317–322.

European Railway Research and Advisory Council, About us. Available at: http://www.errac.org [Accessed June 20, 2017].

European Railway Research and Advisory Council, 2007. *Strategic Rail Research Agenda 2020*, Brussels. Available at: http://www.vialibre-ffe.com/PDF/errac07.pdf.

European Railway Research and Advisory Council, 2014. *Strategic Rail Research and Innovation Agenda*, Brussels. Available at: http://www.errac.org/wp-content/uploads/2014/11/CER_FosterRailReport.pdf.

European Union Agency for Railways, 2016. *Railway Safety Performance in the European Union*, Valenciennes. Available at: https://erail.era.europa.eu/documents/SPR.pdf.

Eurostat, 2017. Opfer des Eisenbahnunfälle nach Unfallart (ERA Daten). Available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=tran_sf_railvi&lang=de [Accessed May 8, 2017].

Farrington-Darby, T., Pickup, L. & Wilson, J.R., 2005. Safety culture in railway maintenance. *Safety Science*, 43(1), pp.39–60. Available at: http://www.sciencedirect.com/science/article/pii/S0925753504000669 [Accessed May 7, 2017].

Gash, S., 2000. *Effective Literature Searching for Research*, Gower. Available at: https://books.google.de/books?id=FFVyQgAACAAJ.

Hart, C., 1998. *Doing a literature review: Releasing the social science research imagination*, Sage.

Huff, A.S., 2008. *Designing research for publication*, Sage.

International Union of Railways (UIC), International Railway Research Board. Available at: http://railway-research.org/About-IRRB [Accessed June 13, 2017a].

International Union of Railways (UIC), Railway Talents. Available at: 13.06.2017.

International Union of Railways (UIC), World Congress on Railway Research. Available at: https://www.sparkrail.org/Pages/WCRR.aspx [Accessed June 13, 2017c].

Janovec, T., 2001. Procedural justice in organizations: A literature map. *Unpublished manuscript. University of Nebraska-Lincoln*.

Jourdan, Z., Rainer, R.K. & Marshall, T.E., 2008. Business Intelligence: An Analysis of the Literature. *Information Systems Management*, 25(2), pp.121–131. Available at: http://dx.doi.org/10.1080/10580530801941512.

Kitchenham, B., 2004. Procedures for performing systematic reviews. *Keele, UK, Keele University*, 33(2004), pp.1–26.

LaPlaca, P.J., 2013. Research priorities for B2B marketing researchers. *Revista Española de Investigación en Marketing ESIC*, 17(2), pp.135–150.

Levy, Y. & Ellis, T.J., 2006. A systems approach to conduct an effective literature review in support of information systems research. *Informing Science: International Journal of an Emerging Transdiscipline*, 9(1), pp.181–212.

Linden, M., von Kortzfleisch, H.F.O. & Arndt, M., 2015. Railway accident costs: determining the value of preventing a casuality by analyzing national investigation body reports. In *The International Symposium on Speed-up and Sustainable Technology for Railway and Maglev Systems*. Chiba, Japan, pp. 1–8.

Maddox, M., 2010. Safety and Security. *DAILYWRITINGTIPS*. Available at: http://www.dailywritingtips.com/safety-and-security/ [Accessed May 17, 2017].

Marketing Science Institute, About MSI. Available at: http://www.msi.org/about-msi/current-member-companies/ [Accessed June 19, 2017].

Marshall, C. & Rossman, G.B., 2014. *Designing qualitative research*, Sage publications.

Okoli, C. & Schabram, K., 2010. A guide to conducting a systematic literature review of information systems research. *Sprouts Work. Pap. Inf. Syst*, 10(26).

Petticrew, M. & Roberts, H., 2008. *Systematic reviews in the social sciences: A practical guide*, John Wiley & Sons.

Railway Saftety and Standards Board, Railway Research UK Association. Available at: http://www.rruka.org.uk/ [Accessed June 13, 2017].

Railway Technical Research Institute, Railway Technical Research Institute. Available at: http://www.rtri.or.jp/eng/rtri/ [Accessed June 12, 2017].

Ridley, D., 2012. *The literature review: A step-by-step guide for students*, Sage.

Schürmann, L., 2017. Das sind die angesehensten Universitäten der Welt. *Manager Magazin*. Available at: http://www.manager-magazin.de/unternehmen/karriere/hochschul-ranking-das-sind-die-angesehensten-unis-2017-a-1152151.html.

Springer, M., What's the difference between safety and security? *TÜV Nord*. Available at: https://www.tuev-nord.de/explore/en/explains/whats-the-difference-between-safety-and-security/ [Accessed May 18, 2017].

Stephan, R. & Aufmkolk, T., 2017. Eisenbahn. *Planet Wissen*. Available at: http://www.planet-wissen.de/technik/verkehr/geschichte_der_eisenbahn/index.html [Accessed June 16, 2017].

Technische Universität Dortmund, 2017. Ausarbeiten der Auswahlkriterien und Erstellen des Ausschreibungstextes. Available at: http://www.tu-dortmund.de/cms/berufung/de/Bewerberinnen-und-Bewerber/Phasen_des_Berufungsverfahrens/17_Phasen/Ausarbeiten_der_Auswahlkriterien/index.html [Accessed June 17, 2017].

Torraco, R.J., 2005. Writing integrative literature reviews: Guidelines and examples.

Human resource development review, 4(3), pp.356–367.

Union des Industries Ferroviaires Européennes, Members. Available at: http://www.unife.org/about-us/members.html [Accessed June 20, 2017a].

Union des Industries Ferroviaires Européennes, Who we are. Available at: http://www.unife.org/about-us/who-we-are.html [Accessed June 20, 2017b].

University of Huddersfield, History of the University of Huddersfield: a timeline. Available at: https://www.hud.ac.uk/175/ [Accessed June 18, 2017].

University of Illinois at Urbana-Champaign, National University Rail Center. Available at: http://www.nurailcenter.org/about/overview.php [Accessed June 13, 2017].

University of Wollongong, UOW History. Available at: https://www.uow.edu.au/about/history/index.html [Accessed June 18, 2017].

Verkehrswissenschaftliches Institut an der Universität Stuttgart e.V., 2010. Eisenbahnlehre.org. Available at: http://www.eisenbahnlehre.org/impressum.html [Accessed June 12, 2017].

Webster, J. & Watson, R.T., 2002. Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, 26(2), pp.8–23. Available at: http://www.jstor.org/stable/4132319.

The list of references in this bibliography is incomplete since all publications which are used for the literature review are not listed in here. This has mainly practical reasons. For the analysis 141 researchers and around 600 to 700 publications are analyzed. Therefore, it would not be appropriate to list all these in the bibliography. The full list of publications is provided in an Excel file structured by allocating each researcher to his university and creating an extra Excel sheet for each of the universities.