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Report 18 (2022)

Analysis of academic education in the rail transport sector

Short Report



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Analysis of academic education in the rail transport sector

Short Report

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Abstract

The German Centre for Rail Traffic Research has commissioned a consortium led by quattron management consulting GmbH to conduct a survey of the current academic teaching and research landscape in the rail transport sector in Germany. Through a survey among university professors, the consortium created a data basis that makes it possible to identify deficits and needs for action. As a key result of the survey, it came out that insufficient visibility of rail transport engineering as a subject of study and insufficient attractiveness of academic careers in the rail transport sector are a considerable problem. Increasing the visibility of teaching and research requires a strengthening of professorships and courses. The creation of additional professorships and the reorientation and reoccupation of existing professorships is necessary in order to be able to offer the entire bandwidth of rail transport engineering in the future. It is essential to improve the teaching and research equipment by additional financial means; this applies equally to universities and universities of applied sciences. The attractiveness of the rail transport engineer profession and related professions should be actively influenced by image-building and low-threshold company-related recruitment and course-specific advertising measures. Overall, the project provides comprehensive recommendations for action to improve higher education in the rail transport sector in the long term.

1 Introduction

In order to meet the Paris climate targets in Germany, the German Climate Protection Act (Klimaschutzgesetz) approved in 2021 stipulates the continuous reduction of greenhouse gas emissions in all sectors, including transport. The coalition agreement between the SPD, Bündnis 90/Die Grünen and FDP confirmed the previous government's decision to increase the modal split in rail freight transport up to 25 percent. Furthermore, it agreed on a doubling of rail transport in passenger traffic by 2030 as a common goal. The targets for passenger transport exceed those of the previous government.

To be noted is that the expansion and sustainable operation of rail transport requires well-trained specialists. Appropriate framework conditions such as financial investments in railways are not enough. Already today, there is a lack of skilled academic personnel, especially engineers, in view of rising demand for well-trained academics in the sub-disciplines rail vehicle construction, railway infrastructure and operations, as well as in the overarching fields of automation and digitalisation. The German Masterplan Railway Transport (Masterplan Schienenverkehr) has identified an urgent need for action in the field of higher education for engineers already in the year 2020.

Railway engineering professorships at universities work in an interdisciplinary manner, especially in the fields of civil engineering, mechanical engineering and electrical engineering. The common goal is to prepare future engineers for the multi-layered professional requirements of the railway industry. Unfortunately, higher education in the railway sector shows numerous bottlenecks and problems that need to be reduced. The German Centre for Rail Traffic Research has commissioned a consortium led by quattron management consulting GmbH to conduct a survey of the current academic teaching and research landscape in the rail transport sector in Germany.

Through a survey among university professors, the consortium created a data basis that makes it possible to identify deficits and needs for action. The inventory of rail education at German universities is documented in the first part of the report. The second part shows the identified deficits and recommendations for action in order to improve higher education in the rail transport sector in a sustainable way.

2 Study conception

For the inventory of the current higher education in railway transport, RWTH Aachen University and quattron management consulting GmbH conducted an online survey in the period from 13.08.2021 to 26.09.2021. The questionnaire was addressed to a group of persons previously agreed with the DZSF. The group of persons included 91 university professors with relations to the rail transport sector located at approximately 40 German universities, universities of applied sciences included. The definition of this group was based on the network of the eleven university professors represented in the project consortium, who are members of the Association of University Professors of Railway Engineering (Vereinigung der Universitätsprofessoren des Eisenbahnwesens, VUE) or the Forum of University Professors in Railway Engineering (Forum Hochschulprofessuren im Bahnwesen, FHB). Additionally, relevant professorships were identified according to the lists of the German platform "Zukunftsbranche Bahn" (Zukunftsbranche Bahn, 2021, pp. 252–293). Furthermore, the consortium identified professorships through extensive internet-based research. The consortium assumes that all professorships relevant to the rail transport sector were registered and contacted.

The survey has been structured into the blocks and topics outlined below in Table 1, next page.

During the survey period, a response of 45 data sets respectively university professorships was achieved. The number of participants corresponds to a share of approximately 50 percent of the persons contacted. The initial contacted group of persons also included professors with activities in research centres, which means that they work with no or with a pausing teaching assignment. These professors stated that they did not wish to participate in the survey, as the focus of the survey is on teaching and less on research. Finally yet importantly, there was no response from honorary professors and only occasionally from those whose retirement is imminent.

Despite the limitations mentioned, the response covers about 90 percent of professorships with an active teaching assignment and dominating research focus in the railway sector. Eleven of the 45 data sets are professorships that offer no courses or only one course with a clear connection to railway engineering. In order to maintain comparability with those professorships having such a focus, the results presented below focus on the reduced number of 34 data records or so-called railway professorships. Twenty-eight of these professorships have railway-specific denominations and offer a particularly extensive range of courses in railway engineering. Another six institutions categorised as railway professorships offer at least two courses in railways; however, they focus not only on railways but also on transport science in a more general sense.

TABLE 1: SURVEY STRUCTURE

Questions blocks	Topics asked (selection)
Details of the professorship	<ul style="list-style-type: none"> ▪ University affiliation and dedication / denomination of the professorship ▪ Funding of the professorship ▪ Existence of honorary professorships and teaching staff ▪ Affiliation to faculties / departments ▪ Classification of the professorship in teaching / research focus
Information on the technical equipment of the professorship	<ul style="list-style-type: none"> ▪ Use of railway-specific technical equipment for teaching and research, e. g. software, railway operations laboratories, test benches, vehicles ▪ Capacities of technical equipment for teaching purposes
Information on the courses offered by the professorship	<ul style="list-style-type: none"> ▪ Fields of Bachelor and Master / Diploma studies offered ▪ Course offerings with reference to railway engineering ▪ International university cooperation / recognitions of degree ▪ Planned changes of the focus of teaching
Information on students at the professorship	<ul style="list-style-type: none"> ▪ Number of examinations / number of students ▪ Information on exchange and foreign students ▪ Number of Bachelor / Master / Diploma theses
Information on research funding at the professorship	<ul style="list-style-type: none"> ▪ Information on the amount of third party funds raised ▪ Information on the origin and percentage share of third party funds ▪ Long-term framework agreements with non-academic partners
Additional information	<ul style="list-style-type: none"> ▪ Number of permanent / third party funded posts at the professorship ▪ Number of doctor theses at the professorship ▪ Number of publications at the professorship ▪ Information on conferences, awards, memberships
Information on demands of the professorship	<ul style="list-style-type: none"> ▪ Demand for railway-specific technical equipment for teaching and research activities ▪ Assessment of the needs for digitalisation at the professorship ▪ Assessment of the staffing situation at the professorship

3 Inventory of higher education in railway transport

Teaching and research at the 34 railway professorships recorded is concentrated at 15 locations. At three of these locations (Aachen, Dresden, München), railway professorships were determined at both universities and universities of applied sciences, at seven locations (Berlin, Braunschweig, Cottbus, Darmstadt, Karlsruhe, Stuttgart, Wuppertal) exclusively at universities, at five locations (Erfurt, Münster, Nürnberg, Wildau, Zwickau) exclusively at universities of applied sciences.

A geographical view reveals an almost non-overlapping distribution of higher education locations in the railway sector across the individual federal states. Only one federal state, North Rhine-Westphalia, has according to the survey more than two such university locations. In several federal states, including the city-states of Hamburg and Bremen as well as Saarland, Mecklenburg-Western Pomerania, Rhineland-Palatinate, Saxony-Anhalt and Schleswig-Holstein, no railway professorships are recorded. Especially in northern Germany, there is a significant gap in the spatial coverage of professorships (Figure 1). Considering the small number of ten university locations and eight university of applied sciences locations (with three overlaps), it can be assumed that the visibility of railway engineering is low compared to other university subjects. According to data from the Federal Ministry of Education and Research (BMBF), there are 424 universities in Germany (BMBF, 2021, p. 43). According to that, railway professorships exist only at less than 5 percent of German universities.

The majority of the 34 railway professorships is associated to the faculties respectively departments of civil engineering and mechanical engineering. Special cases are the TU Dresden (Faculty of Transport Sciences), the TU Berlin (Faculty of Transport and Machine Systems), the UAS Erfurt (Faculty of Economics, Logistics and Transport), the TH Wildau (Faculty of Engineering and Natural Sciences) and the UAS Zwickau (Faculty of Automotive Engineering).

The 34 railway professorships were asked to allocate their teaching activities in the rail transport sector to one or more sub-discipline (vehicle technology, propulsion technology, railway infrastructure, control and safety systems, railway operations, transport and logistics). The result shows that all 15 locations offer at least two sub-disciplines. Eight locations (Aachen, Berlin, Darmstadt, Dresden, Erfurt, München, Nürnberg, Stuttgart) cover at least five sub-disciplines. Three locations (Braunschweig, Cottbus, Wuppertal) offer four sub-disciplines, four locations (Karlsruhe, Münster, Wildau, Zwickau) offer two or three sub-disciplines (Figure 1).

The most frequently represented bachelor's degree programmes at university railway professorships are civil engineering, transport and industrial engineering followed by mechanical engineering (Figure 2). Civil engineering as well as transport and industrial engineering also dominate the master's and diploma degree programmes at university railway professorships (Figure 3). For the railway professorships at universities of applied sciences, there is no clear accumulation of certain study programmes. Compared to the university professorships, courses at universities of applied sciences are anchored in a smaller number of degree programmes.

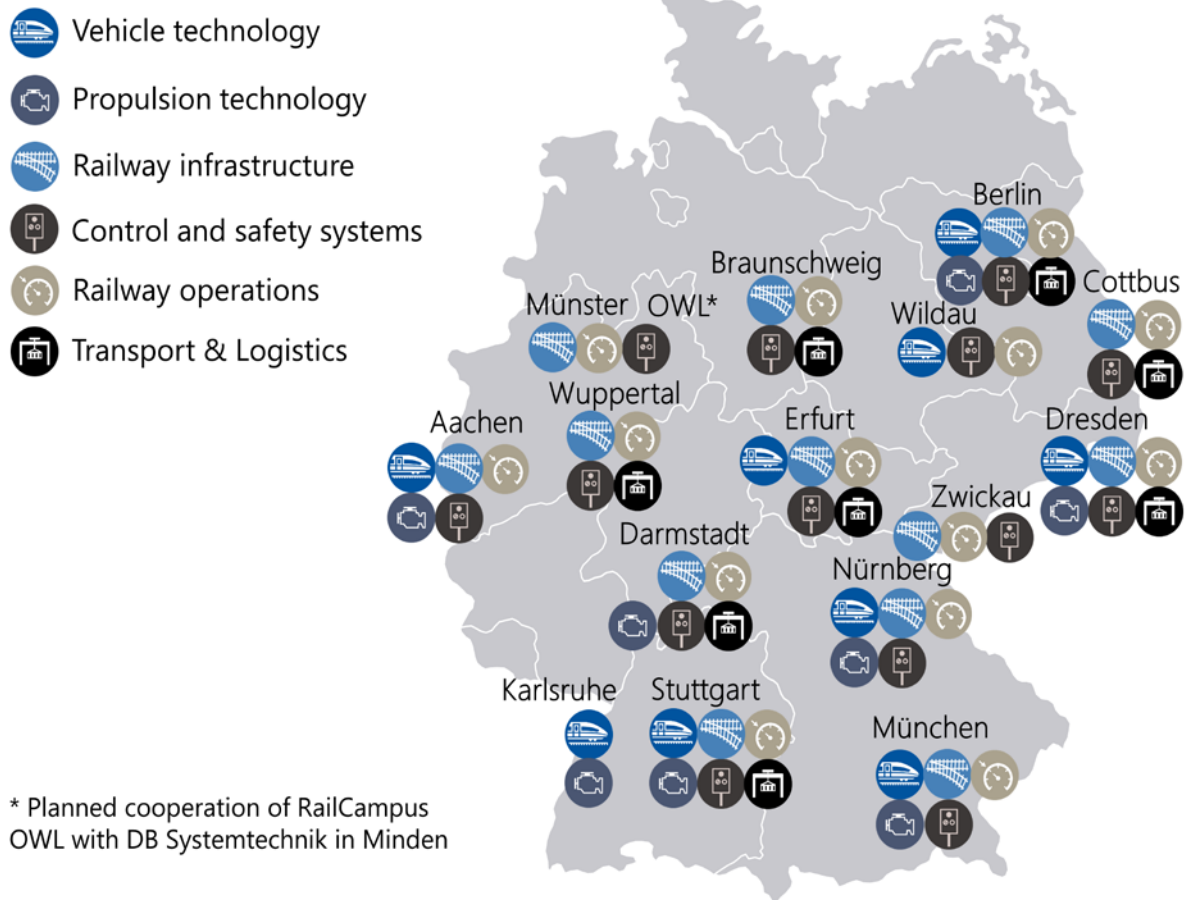


Figure 1: Focus of teaching at the surveyed railway engineering professorships

Please indicate in which bachelor's degree programs your course is offered (multiple responses):

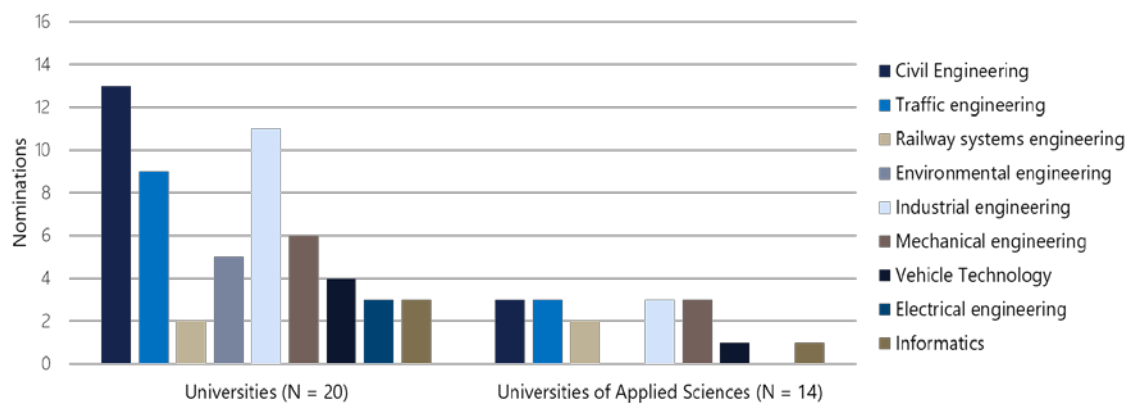


Figure 2: Courses offered in bachelor's degree programs at railway engineering professorships

Please indicate in which master's or diploma programs your course is offered (multiple answers):

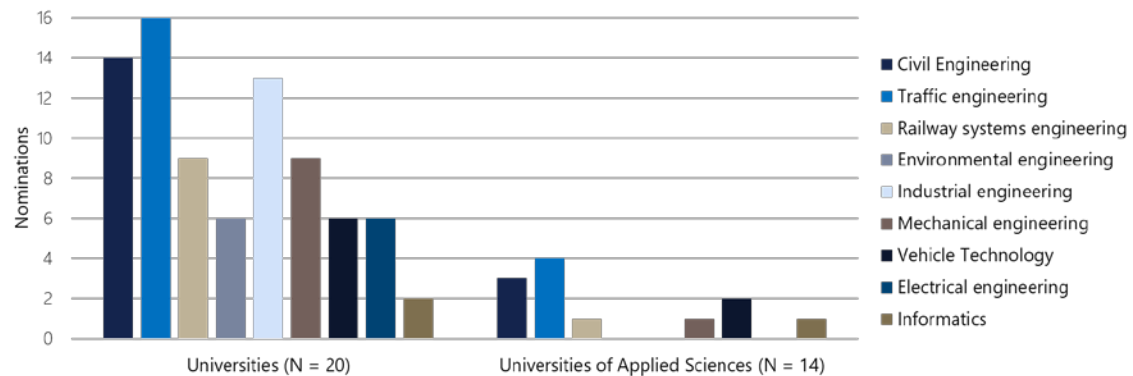


Figure 3: Courses offered in master's and diploma programs at railway engineering professorships

In further detailed questions, the number of student examinations in the academic year 2020/21 was queried. In total, 9579 exams were taken during this period. On average, 345.6 exams were taken at universities and 190.5 at universities of applied sciences. Half of the railway professors at universities have taken between 50 and 249 examinations in this period. The crucial factor for examinations of this magnitude is the embedding of railway-related lectures in volume study programmes such as civil engineering, mechanical engineering or electrical engineering. Six other professorships reported 250 - 500 examinations, four other professorships more than 500 examinations. Very high numbers of cases result for the most part of high-volume lectures in the above-mentioned degree programmes, some of which have far more than 100 students per semester, but also by the reputation of these degree programmes at universities such as RWTH Aachen, TU Darmstadt, KIT Karlsruhe or TU München. In the group of professorships at universities of applied sciences, four professorships report fewer than 50 examinations, five report 50 - 249 and five report 250 - 500 examinations (Figure 4).

How many students have you examined at your chair in the academic year 2020/21?

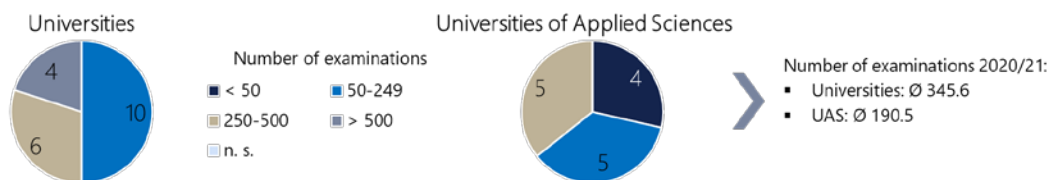


Figure 4: Number of examinations at railway engineering professorships

Among the 34 railway professorships, the use of specific technical equipment was recorded, including the use of high-performance computers, railway-specific software, railway operations laboratories with physical model-scale track infrastructure and interlocking, simulation environments for virtual recreation of railway operations, railway driving simulators, different test benches (e. g. for quasi-static or dynamic testing), operational railway infrastructure (e. g. sidings, marshalling yards, test tracks) and rolling stock.

The results show that railway-specific academic teaching and research at several professorships (e. g. at Münster University of Applied Sciences, Wuppertal University) can be managed without the use of such equipment. Particularly extensive use of equipment can be seen at the university locations of Aachen, Berlin, Dresden, Nürnberg and Stuttgart. The locations of Braunschweig, Cottbus, Darmstadt, Karlsruhe, München and Wildau each use several of the requested facilities, but there are gaps in different areas. In the case of TH Wildau and FH Zwickau, it must be taken into account that professorships have only recently been established, so equipment still needs to be procured (Figure 5).

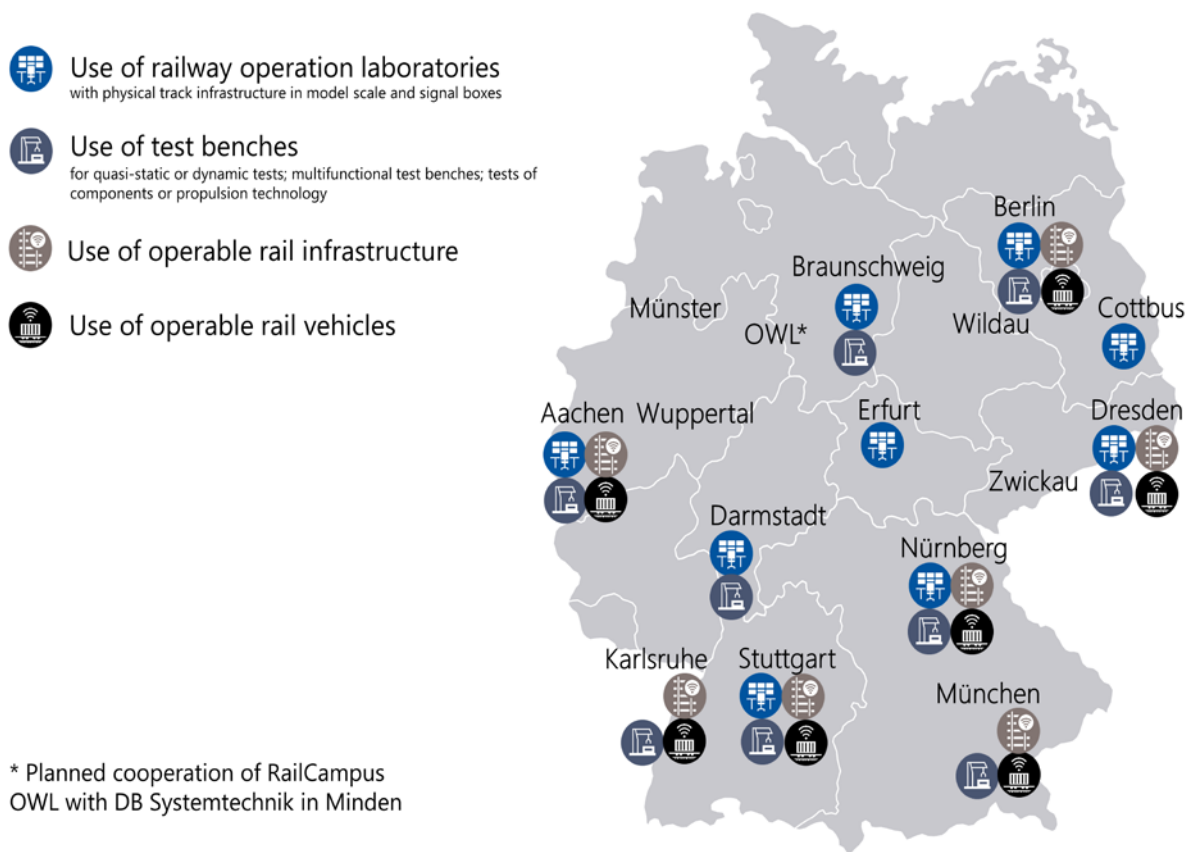


Figure 5: Use of technical equipment at the surveyed railway engineering professorships

In addition to the use of certain equipment features, the consortium recorded equipment needs at the railway engineering professorships. The evaluation shows that needs exist at almost all university locations. A particularly extensive need in at least five different categories was reported at eight universities (RWTH Aachen, FH Aachen, TU Berlin, TU Dresden, FH Erfurt, TH Nürnberg, Universität Stuttgart, TH Wildau, FH Zwickau). Only five professorships stated no demand in any category. When considering the needs of all professorships, specific categories are particularly prominent: Test benches or access to workshops (13 mentions), access to operable track infrastructure (11 mentions), railway-specific software (11 mentions), access to operable rail vehicles (10 mentions), simulation environments for virtual recreation of railway operations (10 mentions) and PC-Pools (10 mentions).

In order to ensure extensive technical resources at a university location, a broad anchoring of railway engineering with several professors on-site is needed. Finally, such an extensive equipment results in a high attractiveness of teaching and the possibility of extensive research activities. Test benches, workshops, track infrastructure and rail vehicles are particularly relevant for the teaching and research activities "vehicle/propulsion technology" and "railway infrastructure". Teaching and research in the fields of "railway control and safety technology" and "railway operations" primarily require railway software as well as physical and virtual laboratories to simulate railway operations and, in some cases, driving simulators or track infrastructure. The less technically oriented research focus "transport and logistics" requires especially software applications.

4 Research at the professorships in railway engineering

The survey identified several research-related key figures with regard to the individual professorships, including the number and financing of employees, information on research-related third party funding and on the extent of scientific publications.

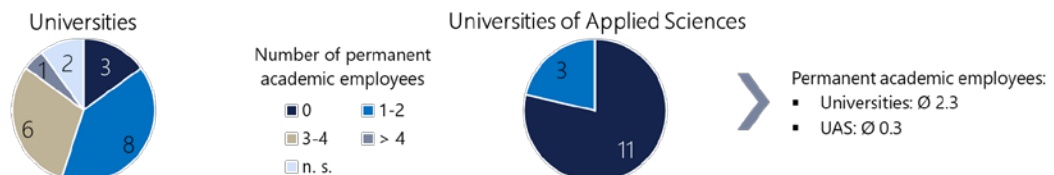
Regarding the number and the financing of employees at a professorship, a distinction was made between permanent and temporary funded positions. Permanent positions are considered in the medium or long-term budget of a university ensuring the minimum number of lessons at a professorship. Third party funding is realised through the acquisition of research funds for a specific period. It should be noted that railway professorships depend on reliable access to research funds from industry and the public sector.

In the group of professorships at universities, there are on average 8.7 academic employees per professorship. This value results from permanent positions for academic employees (Ø 2.3 per professorship) and to a significant extent from third party funded positions (Ø 6.4 per professorship). In addition, an average of 2.1 employees per professorship subsist in technology and administration. This value consists of permanent positions (Ø 1.7 per professorship) and third party funded positions (Ø 0.4 per professorship).

Among the professorships at universities of applied sciences, there is an average of 1.6 academic employees per professorship. The value is composed to a small extent from permanent positions (Ø 0.3 per professorship) and for the most part from positions financed by third party funds (Ø 1.3 per professorship). In addition, an average of 1.1 employees exists in technology and administration. This figure is made up primarily of permanent positions (Ø 0.7 per professorship) and to a small extend of third party funded positions (Ø 0.4 per professorship).

The following diagrams show the frequency of a certain order of magnitude of permanent positions (Figure 6) and third party funded positions (Figure 7) per professorship.

What is the number of permanent posts of academic employees at your professorship in the academic year 2020/21?



What is the number of permanent posts of technical and administrative employees at your professorship in the academic year 2020/21?

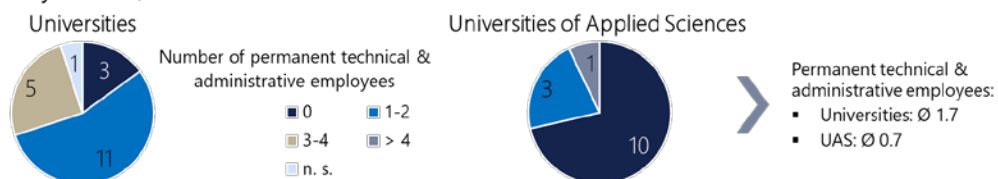
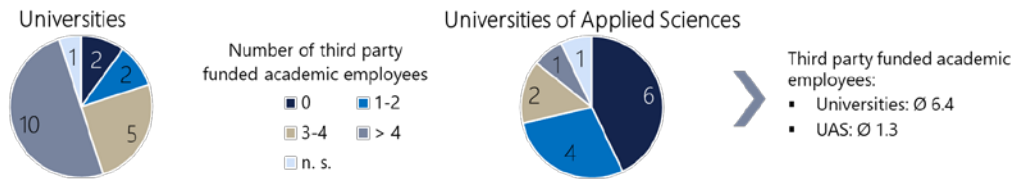


Figure 6: Number of permanent positions at railway professorships

What is the number of third party funded academic employees at your professorship in the academic year 2020/21?



What is the number of third party funded technical and administrative employees at your professorship in the academic year 2020/21?

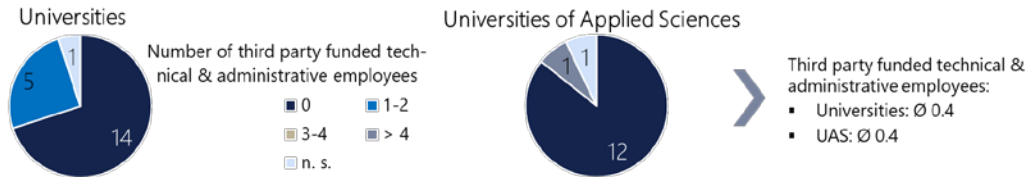


Figure 7: Number of third party funded positions at railway professorships

The information on research-related third party funding was differentiated according to the amount, origin and percentage of total third party funding per professorship. In addition, the significance of public basic funding for research projects was recorded. It becomes visible that the significance of these funds is marginal. For ten university and eight university of applied sciences professorships, this share is less than 10 percent. Conversely, only five professors at universities and two professors at universities of applied sciences report shares of at least 30 percent (Figure 8).

What proportion of your research is financed by basic public funding?

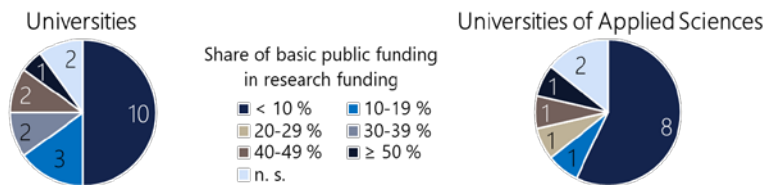


Figure 8: Importance of basic public funding for research at railway professorships

The information of third party funds includes those funds that railway professorships have added to the university coffers in 2020. Half of the university railway professorships acquired third party funding of less than 0.5 million euros. Four university professorships raised 0.5 to 1.0 million euros and two other professorships raised more than 1.0 million euros. Among the professorships at universities of applied sciences, four professors stated that they had not raised any third party funding. Two professors at universities of applied sciences reported less than 0.5 million euros and three professors reported 0.5 to 1.0 million euros (Figure 9).

How much third party funding (in EUR) did you raise in 2020?

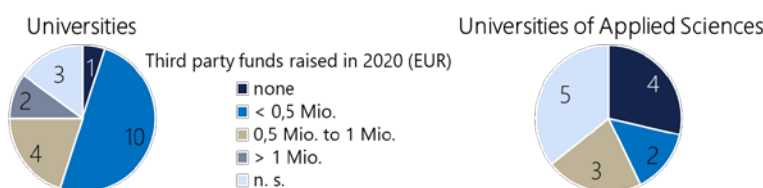


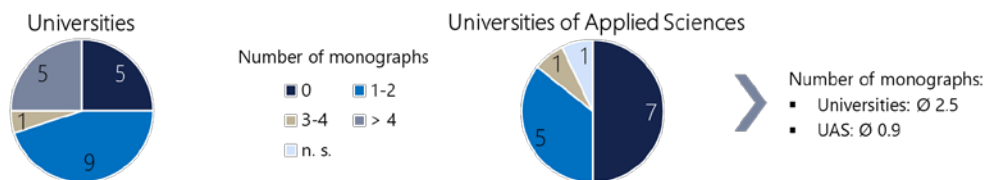
Figure 9: Amount of third party funds raised in 2020 at railway professorships

A relevant parameter for assessing the research performance of a professorship is the number of publications. The consortium recorded these according to the type of publications for the period 2015 - 2020. A distinction was made between monographs, non-peer-reviewed articles, peer-reviewed articles and conference papers.

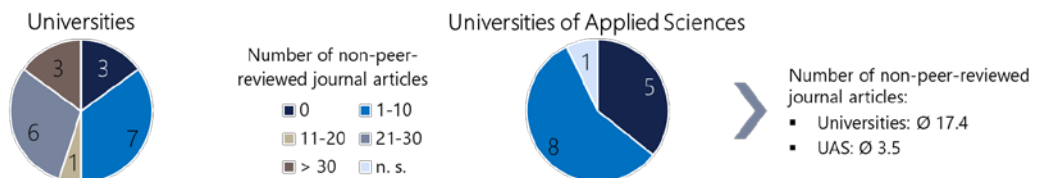
In the group of 20 university professors, an average of 2.5 monographs, 17.4 non-peer-reviewed articles, 6.1 peer-reviewed articles and 13.0 conference papers was published per professorship in the years 2015-2020. Five university professors stated that they had not published any monographs or peer-reviewed articles during this period. Three university professors indicated this for non-peer-reviewed articles and one for conference papers (Figure 10).

The group of 14 professors at universities of applied sciences achieved an average of 0.9 monographs, 3.5 non-peer-reviewed articles, 1.6 peer-reviewed articles and 3.7 conference papers per professorship in the years 2015 - 2020. Compared to university professorships, there are significantly fewer publications across all publication types. Seven professors at universities of applied sciences stated that they had not published any monographs during the period. Five professors indicated this for non-peer-reviewed articles, six for peer-reviewed articles and four for conference papers (Figure 10).

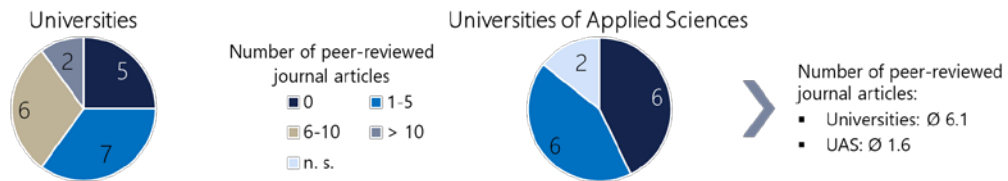
What number of monographs have you published in the last 5 years at your chair?



What number of non-peer-reviewed journal articles have you published in the last 5 years at your chair?



What number of peer-reviewed articles in international journals have you published in the last 5 years at your chair?



What number of conference papers have you published in the last 5 years at your chair?

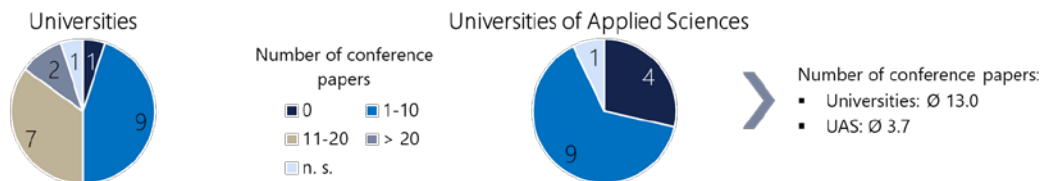


Figure 10: Breakdown of publications at railway professorships

5 Analysis of the need for academic professionals in the rail transport sector

Professorships of railway engineering educate engineers for almost the entire railway-related labour market. Academic professions related to railway transport exist in particular in the fields of railway construction, railway operations and rolling stock, as well as in the overarching fields of automation and digitalisation. Due to the heterogeneity of academic professions in the rail transport sector, quantifying the current workforce and personnel requirements is associated with considerable challenges.

Current data on employees in the rail sector is provided by the study “Analysis of the economic importance of the German railway sector based on its employment effects” (Böttger et al., 2021) commissioned by the DZSF and published in October 2021. The study design made it possible to extrapolate the direct employment in rail transport to currently 397,600 full-time equivalents (FTE) across all professional qualifications. Of the 397,600 FTE, significant shares are accounted by the fields of activity “railway operations” (31 %), “railway infrastructure” (27 %), “other services” (23 %) and “rolling stock”, i. e. rail vehicles (16 %). Of marginal importance are the fields of activity “combined transport” (1.6 %) and “research, supervision, regional authorities etc.” (0.8 %). The study also provides information on the proportion of direct employees with an academic degree. Overall, the proportion of academics is 24.3 percent or 96,763 FTE. Most academics work in the fields of “other services” (39,044 FTE), “railway infrastructure” (20,729 FTE), “railway operations” (17,528 FTE) and “rolling stock” (15,600 FTE) (red markings in Figure 11; for reasons of clarity, non-academic professional qualifications are not specified in the outer circle of the diagram). The study does not allow any statements to be made on the share of engineers among academics.

Until now, relatively few stakeholders have addressed the future academic staffing needs within the rail transport sector in public. The Association of German Railway Engineers (Verband Deutscher Eisenbahn-Ingenieure e. V. - VDEI) assumes that there will be approximately 33,000 new positions to be filled by engineers in the rail transport sector by 2030 (VDEI, 2019, p. 5). The high demand is justified,

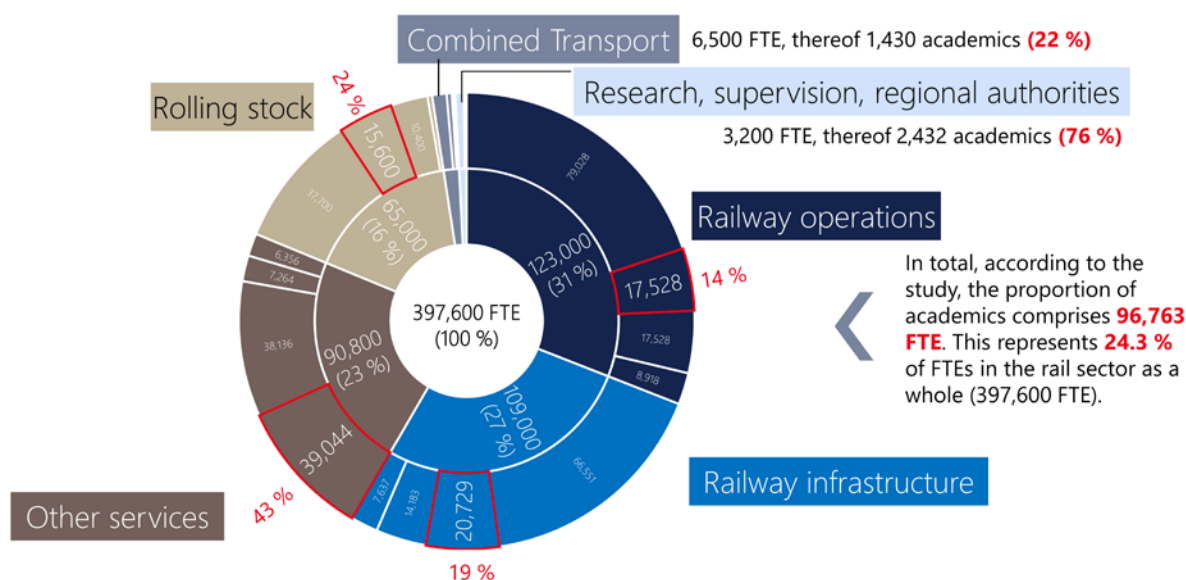


Figure 11: Share of academics in direct employment in the rail sector

among others, by the politically forced expansion of the railway infrastructure and transport, the corresponding innovation and job dynamics and the demographic change on the labour market, which is clearly perceivable. A similar perception contains the final report of the Future Alliance for Railways (Zukunftsbündnis Schiene) from 2020, according to which the railway administration of the federal and state governments expect a large demand for engineers which will be far above the experts available (BMVI, 2020a, p. 63). Other sources address a need for railway engineers qualitatively. Among those are the industry survey of the Association of German Transport Companies (Verband Deutscher Verkehrsunternehmen - VDV) (VDV, 2020), the already mentioned DZSF study „Analysis of the economic importance of the German railway sector based on its employment effects“ (Böttger et al., 2021) as well as the „Sector Analysis of the Rail Industry“ (Branchenanalyse Bahnindustrie) from 2016 (Neumann & Krippendorf, 2016).

In addition to the evaluation of studies focusing on the need for professionals in the railway sector, the consortium has analysed selected job portals related to engineering professions in the sector. For example, the German railway infrastructure company DB Netz AG has been advertising a large number of academic positions for several years. Job offers are – among others - addressed to civil, environmental, industrial and electrical engineers. In addition, there is an increasing demand for testing experts or specialists in the introduction and operational testing of new technologies. Another job engine in the rail transport sector are the vehicle manufacturers, whose business field includes the construction and maintenance of rail vehicles. These companies are currently looking in particular for electrical engineers, computer scientists and mechanical engineers with a focus on vehicle technology and other engineering disciplines. The job profiles addressed are diverse and include, for example, the development, testing and system integration of vehicle components or the commissioning of rail vehicles.

In view of the sources mentioned, the consortium conducts that the demand for academic specialists in the rail sector will increase in the coming years. However, since the data situation is unspecific, studies on the demand for engineers and other academic specialists in the rail sector should be carried out regularly and quantitatively sharpened in future. The current data situation also does not allow any statements to be made on the need for specific qualifications within the engineering professions that apply to the sector as a whole. Nevertheless, the overview analysis of job advertisements makes it clear that engineering degrees in the railway sector are already in extensive demand today.

6 Recommendations for action

The evaluation of the collected data in Germany shows that compared to other academic disciplines, a relatively small number of railway professors can also claim relatively low student numbers and research funds. In addition, there is a gap in certain railway sub-disciplines at several universities and an extensive need for technical equipment. Some professorships - and particular professorships at universities of applied sciences - employ hardly any academic staff. Expansion and funding strategies within universities often concentrate on subjects with high student numbers and research conditions that are particularly favorable. As a result, railway engineering does not receive sufficient attention from higher educational policy. A significant increase of the number of students at railway professorships and improved funding for academic teaching and research will hence provide the basis for strengthening railway engineering as an academic discipline.

An increase in the number of students at railway professorships will have a positive effect on the number of railway-related bachelor, master and diploma theses and will encourage career entries into the railway-related labour market. Study programs that are particularly oriented towards the railway sector should therefore be strengthened. Furthermore, faculties should anchor railway engineering as a subject more extensively in Bachelor degree programs. In addition, a stronger internationalisation of teaching, e. g. through international Master programs, and a more intensive recruitment of students is necessary. The visibility of railway engineering as an academic discipline should be increased overall. A growing reputation of the railway sector will also contribute to higher company investments in railway-related teaching and research at universities.

When considering the labour market, a considerable demand for academic specialists in the rail transport sector can be determined. With reference to the given literature sources, this demand will continue to increase in the future. It is assumed that there will be a high four-digit number of vacancies to be filled each year, compared to only a few hundred graduates with a specialisation in railway engineering. An increase in the number of students in the railway sector is required already now with regard to the labour market. In view of the environmental and transport policy objectives agreed in the German coalition agreement, there is also political pressure to act. If teaching of a significantly higher number of students is not possible in the coming years, the intended expansion of rail infrastructure and the increase of modal split share in rail traffic will hardly be feasible.

In order to meet the actual and future demand for qualified specialists in the railway sector, the current university landscape must be significantly valorized and redesigned. To strengthen railway-related teaching and research, the authors developed the concept of lighthouse and focal point locations. This concept provides for the establishment of additional professorships and the deployment of technical equipment. The implementation of this concept will not succeed without endowed professorships, special funding programs and the financial participation of the German government and the Länder. Successful approaches, e. g. the financing of endowed professorships by rail companies or publically funded rail research centers (RailCampus OWL Minden, Smart Rail Connectivity Campus Annaberg-Buchholz) should be taken up and continued. Likewise, the funding of endowed professorships envisaged in the German Rail Transport Master Plan with the financial participation of the German government and the Länder should be implemented as quickly as possible (BMVI, 2020b, p. 61).

Lighthouse locations should serve to make railway engineering more visible and attractive as a subject with a promising future. For this purpose, it is particularly suitable to use the outstanding reputation of large universities to attract students and researchers from Germany and worldwide. Lighthouse locations should ensure particularly comprehensive teaching and research activities in all railway sub-disciplines. The aim of the focal point locations should be to represent the subject of railway engineering across the country, i. e. at medium-sized teaching and research locations, and to attract students and

researchers in regional catchment areas. Focal point locations should concentrate on application-oriented teaching and research activities in selected areas of railway engineering.

For both location categories, minimum requirements were formulated for staffing, the scope of teaching and research (Table 2). Those requirements were applied to the existing German higher education landscape in order to be able to determine the degree to which these requirements are already met and to assess future needs for action.

TABLE 2: MINIMUM REQUIREMENTS OF UNIVERSITY LIGHTHOUSE AND FOCAL POINT SITES OF RAILWAY ENGINEERING

	Minimum requirements of university lighthouse sites	Minimum requirements of university focal point sites
Staffing	<ul style="list-style-type: none"> ▪ ≥ 2 university professorships (W3) ▪ ≥ 20 scientific employees in railway engineering 	<ul style="list-style-type: none"> ▪ ≥ 2 university professorships (in particular universities of applied sciences) ▪ ≥ 5 scientific employees in railway engineering
Anchor- age of teaching	<ul style="list-style-type: none"> ▪ Extensive range of courses in all relevant sub-disciplines (in particular rail-road construction, railway infrastructure, timetabling, railway control and safety technology, rail vehicle construction and propulsion technology) ▪ Existence of an undergraduate degree program in traffic engineering or similar ▪ Broad anchoring of railway-specific teaching in ≥ 4 degree programs and ≥ 25 modules ▪ Ø ≥ 50 railway-related degree theses/year (Bachelor/Master) 	<ul style="list-style-type: none"> ▪ Extensive range of courses in at least 50 % of the sub-disciplines ▪ Existence of an undergraduate degree program in civil engineering, mechanical engineering or similar ▪ Broad anchoring of railway-specific teaching in several degree programs ▪ Ø ≥ 25 railway-related degree theses/year (Bachelor/Master)
Anchor- age of research	<ul style="list-style-type: none"> ▪ Extensive research in all sub-disciplines ▪ Basic research and application-oriented research ▪ Use of operation laboratories, test benches, rail vehicles and railroad infrastructure for research purposes ▪ Ø ≥ 50 railway-specific publications/year* ▪ Ø ≥ 3 doctoral theses/year 	<ul style="list-style-type: none"> ▪ Extensive research in several sub-disciplines ▪ Application-oriented research ▪ Use of operation laboratories, test benches, rail vehicles and railroad infrastructure for research purposes ▪ Ø ≥ 25 railway-specific publications/year* ▪ Strengthening of cooperative doctoral theses

* In the case of lighthouse sites, a higher number of contributions to basic research is expected compared to focal point sites.

Eight university locations, namely Aachen, Berlin, Braunschweig, Darmstadt, Dresden, Karlsruhe, München and Stuttgart, are suitable as future university lighthouse locations due to their teaching and research-related key figures. At the same time, there is a need for additional professors at these locations. The establishment of new professorships at universities is necessary to expand teaching and research to all relevant fields of railway engineering. Due to the imminent retirement of some professors, it is also necessary to ensure that university professorships will be reoccupied in time. The universities of Braunschweig and Darmstadt have already initiated or implemented new professorships in railway engineering in order to be able to cover a larger number of railway sub-disciplines in the future. In addition to the establishment or further perpetuation of railway-related professorships, in some cases existing professorships should significantly improve their personnel and technical equipment.

Eight other locations of higher education in railway engineering, including two university locations (Cottbus, Wuppertal) and six universities of applied sciences (Erfurt, Minden, Münster, Nürnberg, Wildau, Zwickau) were identified as future focal point sites. Also here, additional professorships should be established in order to fulfill the minimum requirements. Equally important is the expansion of railway-related teaching, for example through dual or career-integrating courses of study, and cooperation with other locations. The latter should be examined in particular in the case of the TU Cottbus and the Bergische Universität Wuppertal. Second, universities of applied sciences should significantly increase their number of employees, especially among scientific staff. In addition, an expansion of research outputs is desirable. Analogous to the railway-related professorships at universities, an improvement in technical equipment is essential.

An increase in the number of students and graduates in railway engineering requires not only an increase in the number of railway-related professorships and an upgrading of the technical equipment, but also an improvement in the attractiveness and visibility of the profession of a railway engineer. A bundle of measures is suitable for this purpose. National and international rail transport campaigns (e. g. Rail summit 2020 of the Federal Ministry for Digital and Transport; annual “Day of the Rail” starting in 2022 in Germany) can contribute to improve public perception and acceptance of rail transport. In principle, large-scale campaigns involve all citizens, including schoolchildren, prospective students and graduates, and can therefore promote decisions to study rail-related subjects or to start a career in the rail sector. Target-group-specific, company-related recruitment measures are effective means of acquiring graduates for a rail transport profession. Low-threshold recruitment, e. g. within the framework of university contact or job fairs, should be expanded. Furthermore, universities and professorships should promote rail-related courses more purposeful in the future. In addition to web-based advertising and information campaigns, suitable approaches include low-threshold contacts with potential students, e. g. as part of Study Information Days or Open University Days.

7 Summary

The survey among university professors in the railway sector in Germany commissioned by the DZSF shows very clearly that their number is relatively low and concentrated at only a few locations. The number of university graduates with railway expertise is accordingly at a rather low level. The demand for academic specialists is currently being met in an extensive manner by graduates without railway-specific expertise. There are serious bottlenecks in filling academic positions in the sector, which will become even more acute in the future.

The survey leads to the recommendation to strengthen railway engineering as an academic discipline, as well as a component of engineering degree programs and as an administrative unit. It is also necessary to continue and expand the personnel and technical equipment of professorships in railway engineering. In order to ensure the targeted creation and reorientation of professorships, the consortium elaborated the concept of university lighthouse and focal point locations and applied it to the existing university landscape. As a result, it can be deduced that new university professorships need to be created. In addition, the number of scientific employees at universities and universities of applied sciences must be increased and the technical equipment of those professorships must be improved in line with demand.

Filling professorships will require various funding instruments at the federal level and the level of the German federal countries, as well as endowed professorships, public-private cooperation and other measures. At this point, stakeholders should pick up successful approaches and multiply them. Increasing the number of students with a connection to the railway sector also requires that stakeholders improve the visibility and attractiveness of railway professions and take image-building measures throughout the whole sector. Finally, politics should have a greater influence on the framework conditions for the profession of railway engineers and related professions.

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