Modelling of Passenger Handling Processes in Railway Stations – A Mixed-Methods Approach

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ABSTRACT

The constantly increasing number of passengers using public transportation leads to an expansion of the services offered by public transportation companies. The existing transportation infrastructures, especially railway stations, can only partly cope with this rapid growth. There is already overcrowding on platforms and access routes, especially during disruptions caused by natural disasters or major public events. This crowding may result in personal injury or shutdown of operations for safety reasons. The research project CroMa aims at improving robustness, safety, security and performance of railway stations at peak loads.

The paper contributes thereto by developing an approach to assess railway infrastructure in terms of the risk of overcrowding. The core of this research is to combine qualitative workshop results with quantitative database analysis. Furthermore, the paper gives an outlook on the ongoing process model development as a basis for a semi-quantitative evaluation tool for railway stations applicable by end users.

Keywords

Crowd-Management, Mixed-Methods, Process Modelling, Critical Infrastructure, Railway Transportation.

INTRODUCTION AND RESEARCH APPROACH

Public transportation is used by an average of 34 million passengers per day in Germany (Federal Statistical Office of Germany 2020). This represents a significant share of the total traffic volume, especially in urban areas. 56 percent of this share is accounted for by rail transportation, as this mode offers a large transport capacity (Federal Statistical Office of Germany 2020). Due to its already great importance for economy and society, rail transportation is regarded as a critical infrastructure in many countries (Adjetey-Bahun et al. 2016; Brem 2015; Federal Ministry of the Interior 2009; United States Department of Homeland Security 2013; United States Department of Homeland Security and United States Department of Transportation 2015).

The rail-bound transportation volume has been rising continuously for several years (Federal Statistical Office of Germany 2019) and it is expected that the number of passengers will continue to increase, especially against the background of expanding urban areas and growing awareness of climate protection and related political restrictions on motorized individual transportation (Fichert 2017). For this reason, many public transportation companies and railway operating companies are reacting by improving their services, either by increasing frequency of service or by reducing fares. This is intended to and is likely to lead to a further increase in passenger numbers. At the same time, however, the adaptation process of the railway infrastructure is being delayed. Since the construction of new railway stations and the modification of existing stations in particular cannot be realized in the short term (Fichert 2017). As a result, the number of passengers in the railway system increases, which in turn may result in the overcrowding of platforms and stations as well as access and exit routes. Some stations are already experiencing this problem (cf. Department for Transport 2015; Schirmer 2018). Overcrowding may result

in injury to passengers in the worst case and in the less severe case, it may make it necessary to shut down operations immediately to control the situation. The consequences for railway operating companies are not only of economic nature (Anderson 2014; Bauernschuster et al. 2014; Faturechi and Miller-Hooks 2015; Federal Ministry of the Interior 2011; Miller-Hooks et al. 2009), but can also seriously affect their image, so it is important to avoid these situations altogether. To do this the cooperation of a large number of stakeholders is required.

The research project CroMa aims at ensuring the safety of individuals, as well as the proper management of major public events and in particular the full performance of the rail transportation system under any circumstances. This includes the preservation of the operational safety of stations, trains and the required technical infrastructure in the face of abnormal conditions. In this context, not only disruptions and incidents should be regarded as abnormal occurrences, but also operations under challenging but still routine or regularly occurring conditions, such as the beginning of holiday season, an increased number of commuters or, as mentioned above, major events.

In this paper, it is examined which disruptive scenarios or disturbance events are of relevance during operations and how they can be evaluated in terms of their criticality for the uninterrupted operation of the rail transportation system. The paper shows the mixed-method approach that has been applied so far. The future objective of this research is to develop a semi quantitative approach for the assessment of critical system interfaces. For this purpose, a qualitative approach has already been carried out within the framework of an expert workshop. This is supplemented by a quantitative database analysis. Furthermore, the paper provides an outlook on the development of a process model as an intermediate step towards the development of the semi-quantitative assessment tool for end users. Figure 1 shows the research process as planned and partly already carried out.

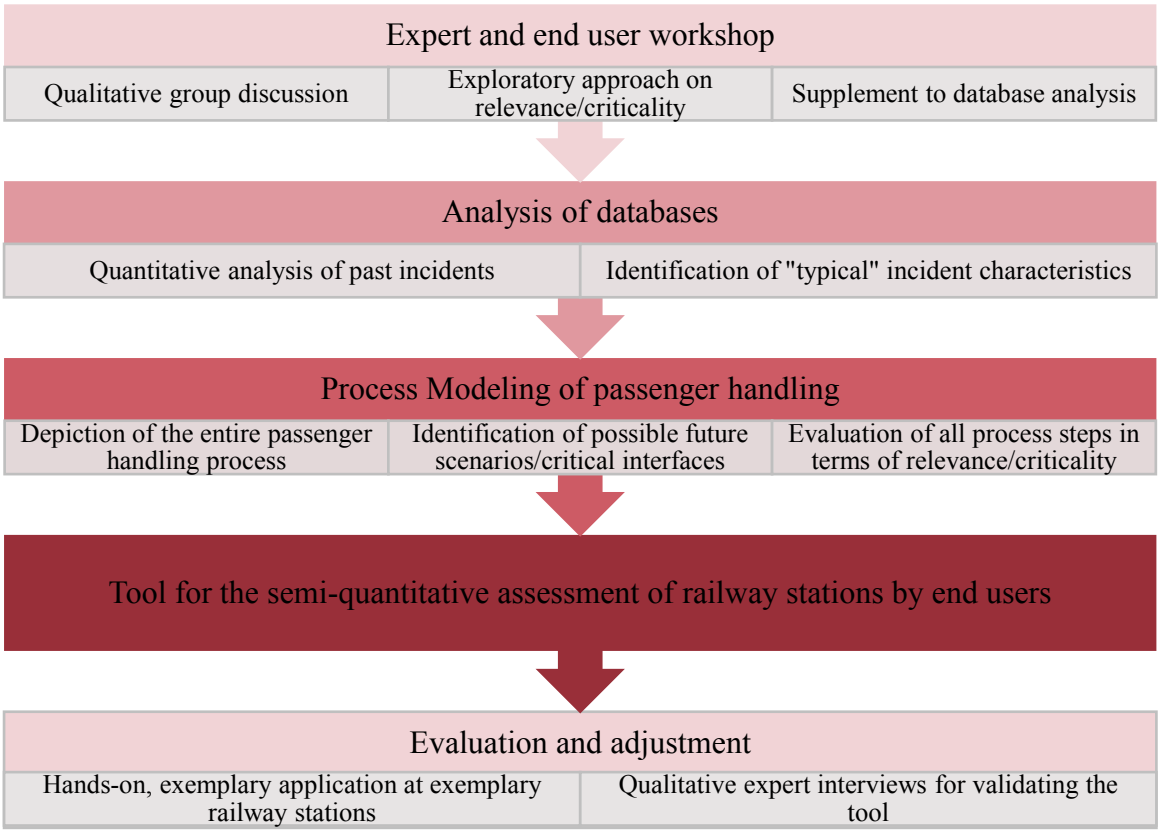

Figure 1. Outline of the proposed research process (source: authors)

EXPERT WORKSHOP ON SCENARIO DEVELOPMENT

Within the project, a workshop was held to determine which incidents are of particular relevance for different stakeholder groups. This was done on the basis of various rough scenario sketches (unplanned or planned occurrences) and their possible effects on transportation infrastructures (short-term or long-term impairments). In the workshop discussion, it was to be worked out which (specific) influencing parameters and factors in each scenario are of interest or particular relevance for the different stakeholders. The term scenario here refers to a rough outline of a disturbance event. Guiding discussion questions have been provided for the experts:

- What special challenges does the sketched scenario pose for you in your specific function or the organization you represent?
- How do you assess the relevance and criticality of the scenario or which alternative scenarios or variables to asses them do you consider to be more critical relevant/ for your specific function or your organization?
- Do you have any experience in dealing with the respective scenario or do you have pre-planning for such events in your organization?

The explorative focus of the group discussion is intended as a preparatory approach for the construction of standardized measurement and evaluation tools such as scales for measuring attitudes (Lamnek and Krell 2010). It can therefore be understood as a complementary method to the subsequent analysis of the databases (cf. section "The indications and key findings from the group discussion are summarized in Table 1. The qualitative workshop results provide an explorative insight into the researched subject. The results allow for a more focused quantitative analysis of past incidents/disturbance events. In the subsequent section, the database analysis is used as an attempt to quantitatively substantiate the qualitative results, where appropriate, before the last section of the paper introduces an approach to integrate the results of both the qualitative and quantitative approach into a process model.

ANALYSIS OF PAST INCIDENTS"). By exploring the opinions and attitudes of individual participants (Bortz and Döring 2006; Lamnek and Krell 2010), it is intended to provide a qualitative reference point for the further development of the process model (cf. section "PROCESS MODELING OF PASSENGER HANDLING") respectively the semi-quantitative tool and finally for the planned end user guidelines. By means of a group discussion, the first step is to identify the issues that end users of different sectors see as particularly challenging and to learn of their experiences.

The results of the workshop shall be integrated back into the development of scenarios and their future modelling. In this context, the workshop will be an independent source to complement the results of the database and literature research. In combination with the literature and database research and the planned expert interviews, combinations of attributes or descriptors will be developed for the scenarios.

Composition of the expert/end user group

It was important for the selection of the experts and practitioners/end users that as many sectors as possible from the context of the CroMa research project are represented. In addition to the directly affected public transportation and railway operating companies, railway infrastructure companies and service providers as well as police and non-police public authorities and organizations with security tasks, event organizers and event security services were therefore also contacted and asked to participate. In addition to the involved partners in the research project, the aim was to win previously non-involved organizations in order to obtain a broader spectrum of experts and an undisguised view of the topic.

As depicted in Figure 2, the 14 participating experts and end users can be grouped among the following six groups or sectors: "Science", "Event organizers/non-police public authorities and organizations with security tasks", "Event security services" as well as "Railway infrastructure companies", "Railway operating companies" and "Local public transportation operators".

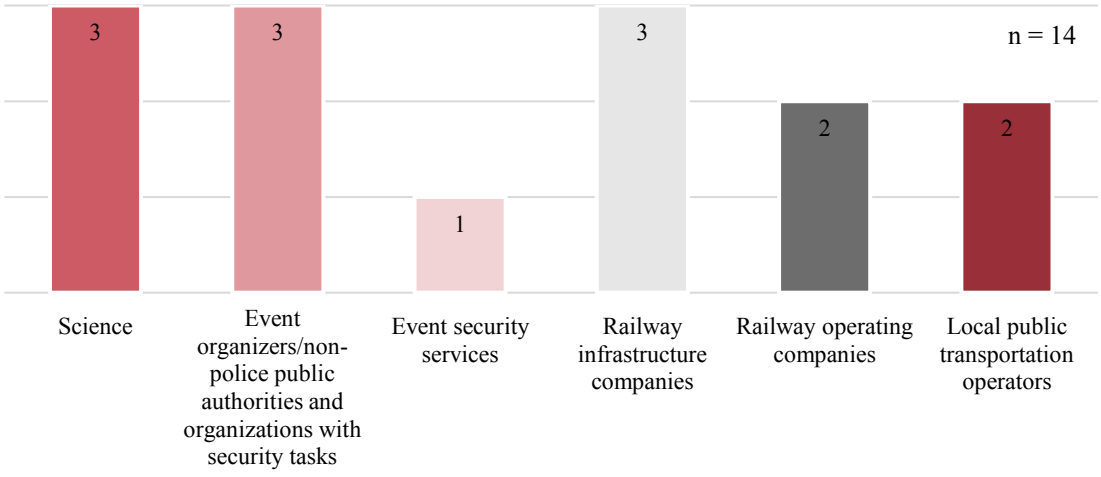

Figure 2. Distribution of experts by sectors (source: authors)

However, no participants could be recruited for the area of police authorities at all. The participation of this group in scenario development needs therefore to be increasingly ensured by conducting expert interviews in that field. Further representatives of railway operating companies, public transportation operators and event security services should also be interviewed subsequently, in order to increase their proportion in the project and to be able to adequately consider their interests and points of view.

The results of the group discussion were collected and analyzed. The transcript of results of the group discussions were subjected to a qualitative content analysis using the MaxQDA software. The evaluation in the subsequent section highlights the results of the discussion and draws a common conclusion from the results.

Workshop results

At the beginning of the workshop, the participants were asked to assess roughly outlined scenarios on a grid. The objective of this question was to learn how participants and experts would perceive the impact of disruptions on their sector or organization from a subjective point of view. For this purpose, the participants were given rough scenario sketches. These scenario sketches distinguished between planned and unplanned as well as short-term and long-term disruptions. In this context, the term "planned" may refer for example to the setting up of a construction site affecting a train station, a major public event or the start of the holiday travelling season. An “unplanned” incident, on the other hand, may involve a storm or damage to railway infrastructure. The temporal dimension differentiates between events with short-term and long-term impacts or disruptions, whereby a construction site, for example, can be attributed to “long-term” impacts and a major event to “short-term” impacts.

The scenarios were neither defined further nor quantified in order to consciously include the subjective and solely qualitative assessment of the participants and thus enrich the quantitative analysis of the databases. The qualitative evaluation of the scenario sketches by participants with regard to their individual relevance resulted in the picture shown in Figure 3, while the evaluation of their individual criticality resulted in the picture shown in Figure 4.

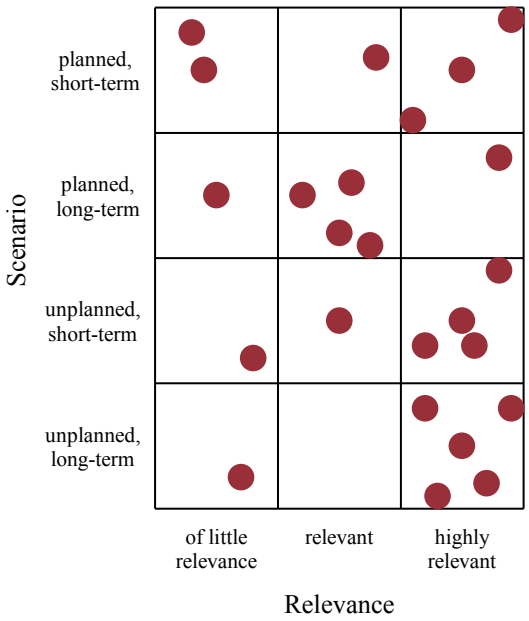

Figure 3. Qualitative assessment of relevance (source: authors)

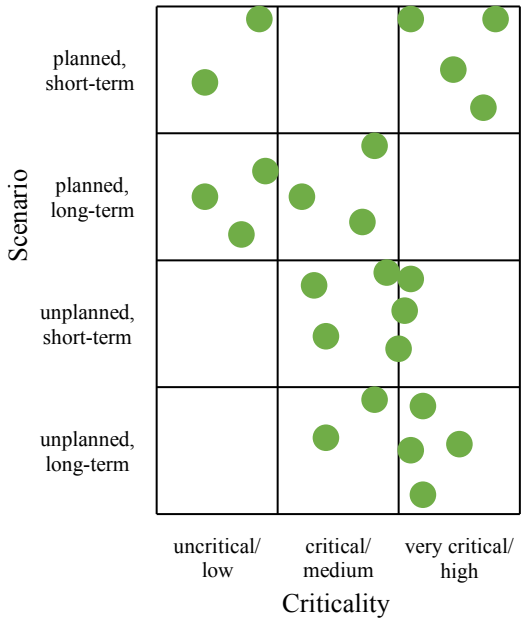

Figure 4. Qualitative assessment of criticality (source: authors)

The results of the qualitative assessments have been clustered by calculating the median of each assessed scenario sketch. As a result of the subjective assessment, the majority of the participants were of the opinion that unplanned events can be dealt with in much the same way as those planned, since the only difference would be the availability of resources. In contrast thereto, long-term events are perceived to be more complex or critical, but not necessarily associated with greater impact (cf. clusters in Figure 5 and Figure 6). The participants also discussed the need to establish a uniform definition of the term "criticality" for both event organizers and railway operating companies, as the respective relevance also differs in some cases. A shift from unplanned to planned events would be possible, provided that sufficiently adaptable plans existed, or experience could be used. The assessment of unplanned occurrences as being potentially more critical is also reflected in the clustering of the assessment compared to those of planned occurrences. Similarly, unplanned occurrences are attributed a higher relevance, although the

ranges or outliers are noticeable in both figures. This may indicate the dissimilar perception or definition of criticality and especially of short- and long-term in different sectors, as pointed out in the discussion.

In this context, it became apparent that the time frames or timelines of rail transport and infrastructure companies on the one hand and event organizers on the other sometimes differ considerably. The same was true for the spatial dimension. Railway operating companies enjoy a much greater degree of flexibility due to their geographically extensive and widespread network. This gives them better opportunities to take evasive action or to compensate for and adapt to disruptions compared to local public transportation operators or even event organizers in a more narrowly defined environment. For the assessment of criticality, the reaction times and delays as well as the respective scope for decision making - partly influenced by external decision makers such as the police - were also discussed. While there are distinct safety guidelines and standardized procedures in railway operations, in crowd management the guidelines are rather diffuse and difficult to verify. An advantage for event organizers is the fact that they usually have a fixed contact person at the regulatory authorities, while railway operation companies do not necessarily have such a person at the event organizers' disposal.

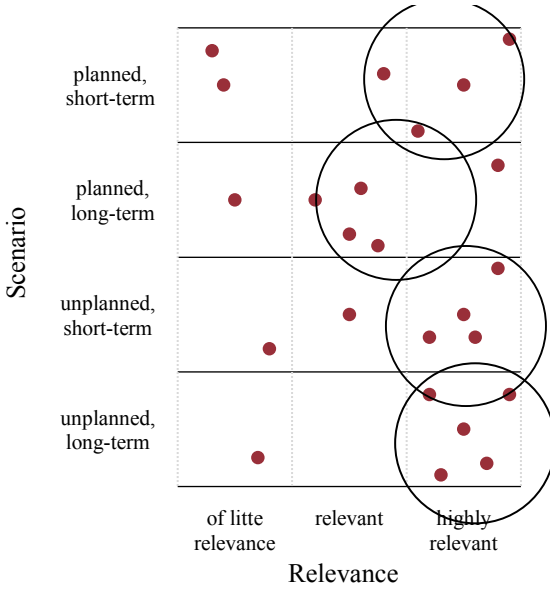

Figure 5. Clustering of relevance assessment (source: authors)

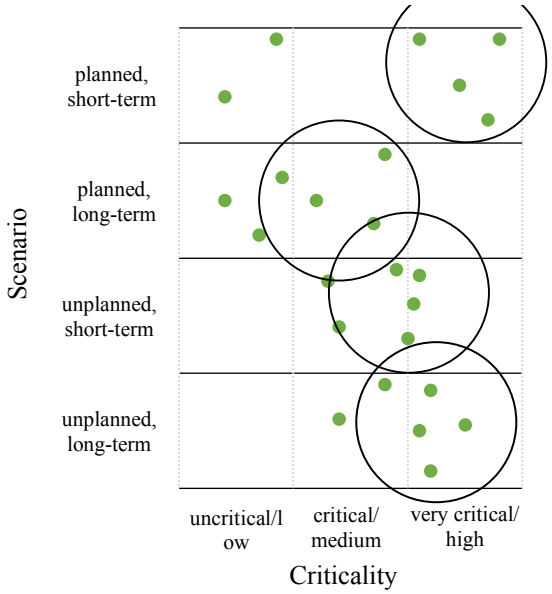

Figure 6. Clustering of criticality assessment (source: authors)

Instead of distinguishing between the two dimensions of "unplanned/planned" and "short/long term", the experts suggested differentiating between infrastructure capacity in terms of available space, available personnel and possible redundancies. In addition - with regard to the guidelines to be developed in the CroMa project in the future - the interfaces of the different timelines should be included. Aspects of economic efficiency, the effective sphere of influence of the infrastructure as well as requirements of the retail area operators should be considered.

Summarizing, the expert and end user working group concluded that even for the same incident the entry points would be different, especially for organizers and railway operating companies. The railway operating companies would have great compensation possibilities owing to a multitude of available resources and the large geographical extent of the network. In contrast, the event organizers or local organizations would have fewer alternative options, which would make it less easy to absorb the impact of one and the same event for them.

In particular, the workshop participants agree that the categorization of scenarios should be diversified and therefore suggest various alternative variables besides plannability, relevance and criticality. Almost all of these variables or measurements focus on the outcome of an event or the possibilities to influence this outcome at all. This indicates that the emphasis is less on the cause but more on the impact or outcome of an event. Due to the mostly matching statements on the transferability of intervention measures from one scenario to the other and the resulting shift from "unplanned" to "planned" scenarios, the experts seem to focus more strongly on the organization-specific intervention options, taking into account the available resources and economic efficiency.

In addition to this output- respectively process-oriented perspective, the question of the different dimensions of time and space as well as the relevance threshold for the individual organization was discussed intensively. A discrepancy in the dimensional definitions between railway companies - which rely on regional or even national systems and therefore have many potential options for reaction - and the more locally or even punctual oriented

actors, such as event organizers or local public transportation companies with only limited compensatory options, has been found to exist. Accordingly, the different stakeholders are of major importance, since their needs and their ability to react to incidents may differ considerably.

The represented organizations draw their experience mainly from recurring or repeated events and not from single or occasional incidents. This is in line with the also agreed statement that there is no structured knowledge management and no reprocessing of incidents but only in semi-structured approaches. However, the participants recognize the advantages of structuring knowledge across all involved sectors, provided that the individual requirements and processes of the respective organizations are sufficiently taken into account. In this context, the tension between exchange and competition should also be considered. The expert group agreed that the need for resources and the sensitivity of the stakeholders involved in the planning and implementation of major events had increased, but that this had neither significantly increased the number of stakeholders to be involved nor the complexity of the process as a whole.

According to the consensus of the expert discussion, the complexity of an incident depends to a large extent on the existence or transferability of already pre-existing, other concepts to the specific scenario, as well as the possible impact and the number of stakeholders involved in the incident. The existence of concepts is believed to have a significant influence on the quality and speed of the reaction to an incident. Exercises as well as preparatory measures and good crisis communication might also contribute to this. On the other hand, unclear demarcation of responsibilities and unknown stakeholders are believed to have a negative impact on the coping capacity.

Table 1. Key findings from the expert/end user workshop

	Key findings	**Comments**
Relevance assessment	planned/short term = no conclusive statement planned/long-term = relevant unplanned/short term = very relevant unplanned/long-term = very relevant	-
Criticality assessment	planned/short term = no conclusive statement planned/long-term = uncritical/critical unplanned/short term = critical/very critical unplanned/long-term = very critical	-
Statement 1	Further dimensions or variables for the clustering of events and a uniform definition of these are necessary.	Reaction times, scope for decisions/options for action, capacity (area, personnel, redundancies), cost-effectiveness, sphere of influence of the infrastructure, complexity, severity, duration, compliance with protection goals, "stress", causal factors, cascade effects and transferability of measures (shift from unplanned to planned if transferable concepts exist).
Statement 2	The time lines, relevance and spatial dimensions for railway operating companies and event organizers differ considerably.	Interface analysis of the time lines
Statement 3	Railway operating companies have a multitude of compensatory options and a high degree of standardization due to their spatial extent, whereas crowd management is often local, less standardized and usually has few alternative options.	-
Statement 4	Long-term occurrences are more complex, but do not have greater consequences or are "worse" than short-term occurrences.	-
Statement 5	Unplanned occurrences can be dealt in the same way as planned, there is only a difference in the urgently available resources.	Preparation for weather-related events, terrorism, bomb threats/unidentifiable objects, premature event cancellation/

		(time-critical) evacuation, overcrowding/redirecting crowds, medical emergencies
Statement 6	Experiences are gathered via routine/learning effects in repeated events, as there is no structured knowledge management.	Establishment of a structured knowledge management, obligation for communication between actors required

The indications and key findings from the group discussion are summarized in Table 1. The qualitative workshop results provide an explorative insight into the researched subject. The results allow for a more focused quantitative analysis of past incidents/disturbance events. In the subsequent section, the database analysis is used as an attempt to quantitatively substantiate the qualitative results, where appropriate, before the last section of the paper introduces an approach to integrate the results of both the qualitative and quantitative approach into a process model.

ANALYSIS OF PAST INCIDENTS

The objective in analyzing databases of past events was to identify and categorize incidents according to their relevance. This was intended to provide a quantitative approach alongside the qualitative results of the workshop. Thereby the main focus was on the question of the most frequently occurring incidents as well as the average duration of the incidents.

The starting point for the analysis was the assumption that, in the event of a disruption or incident, a train does not arrive at a particular station on time or not at all or is unable to maintain its scheduled timetable. Based on this assumption, after an initial search for incidents on Twitter and news websites, attributes were developed which allow for the classification of such incidents. These attributes include the size of the railway station (according to the station categorization of Deutsche Bahn), the plannability of the incident (unplanned vs. planned), the duration of the disruption (short < 2h, medium < 24h, long > 24h) and which additional safety measures were necessary to handle the disruption (no measures, extended measures such as partial track closure, full closure). For the analysis of a sample of 982 incidents, consisting of datasets provided by a railway operating company as well as reports from the public media was available. A distinction was made between the incidents according to the type of transportation means (high-speed train, commuter train, freight train, etc.), the actual duration of the disruption (in hours) and the generic incident/scenario category. The events in the database were correspondingly typified according to categories and these were examined with regard to their frequency of occurrence, their plannability and the place where they occur as well as their temporal extent.

Based on the preliminary scenario sketches from the workshop and the input from expert speakers, the following generic incident/scenario categories for the clustering of events were defined:

- Construction works/refurbishment works,
- Bomb threat/defusing,
- Fire (e.g. train on fire, fire affecting the rail network),
- Special ride (e.g. extra train for a soccer game),
- Accidents involving persons/medical emergencies,
- Criminal offences (e.g. Hostage-taking, Uncertain threat situation/terrorist threats, accidents involving persons with external causes),
- Track closure (e.g. train broken down),
- Strike,
- Technical defect (e.g. incidents involving the catenary, obstacles on the track),
- Storm,
- Derailment.

Figure 7 shows the absolute and relative frequency of an incident category in the entire sample as a result of the database search. With a relative frequency of about 46.8 percent, technical failures were the most prominent of all occurrences examined, with construction works of about 36.6 percent being the second highest incident category. All other scenario categories are represented with relative frequencies of between one percent and three percent. Although they all together make up the main part of the categories in terms of quantity, they play a rather subordinate role when considered individually.

Also, whether a scenario category occurs as planned or unplanned depends on the individual incident. In most cases, however, an occurrence happens unplanned, which may also be due to the underlying categories of the scenarios. It also turned out that no specific railway station category or station size could be attributed to a certain scenario. This is because these events occur at too many different train station sizes or because they are single

events or the frequency of their occurrence is too low. Although slightly higher probabilities of occurrence at larger railway stations can be identified for some types of scenarios, this assertion is not yet sufficiently proven statistically and requires continued database analysis. Thus, the analysis does not yet allow any precise conclusions to be drawn about a specific station category for events or scenarios.

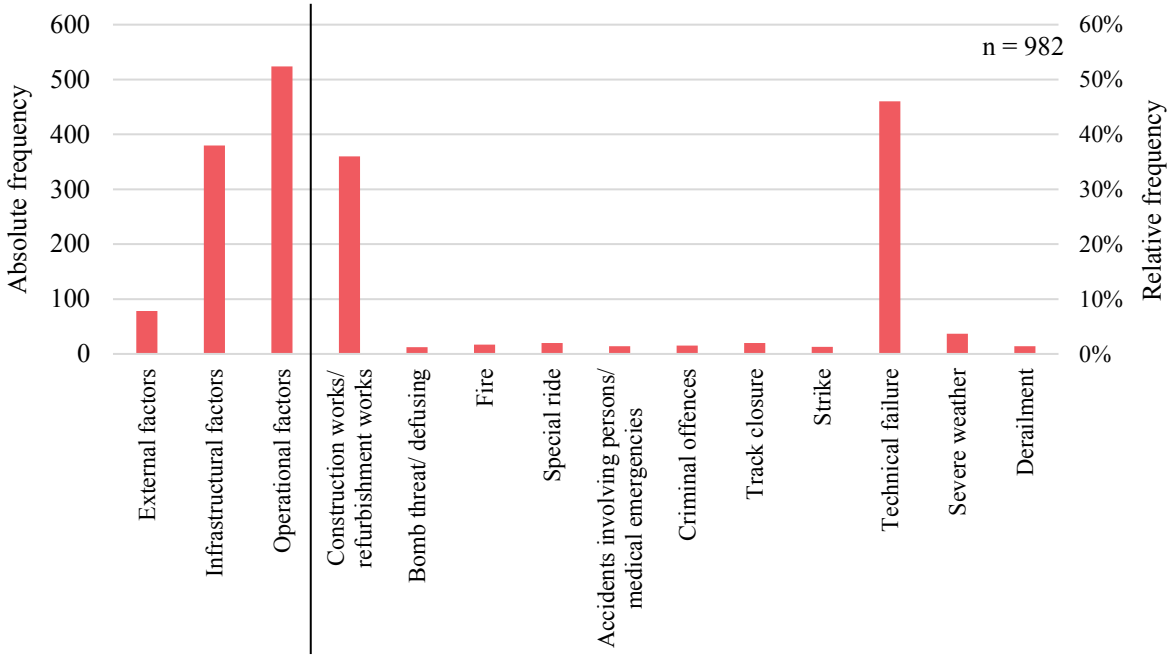

Figure 7. Frequency of incidents in the sample (source: authors)

For the duration of an incident, the starting point of the occurrence and thus the beginning of the disturbance, as well as the announced end of the incident were assumed to be the time frame. The average value of all analyzed occurrences was 232 hours, but is already afflicted with a standard deviation of 427 hours. This is partly due to the fact that the different types of incidents can be dealt with at different speeds. For example, disruptions due to construction works can last for several days and weeks or even months (in this case the mean value is 2324 hours with a standard deviation of 1445 hours). On the other hand, disruptions can also be dealt with within a few hours, for example in the case of injuries to passengers or criminal offences in the railway station area (two to three hours with a standard deviation of one or two hours). Figure 8 shows the average duration of the disturbance per incident/scenario category and the corresponding standard deviation (black cross) as a result of the database analysis. The information is given in hours. Just as with the localization of incidents and their plannability, no definite and confirmed correlations between frequency of occurrence and duration of disruptive events and the individual scenario categories could be ascertained overall.

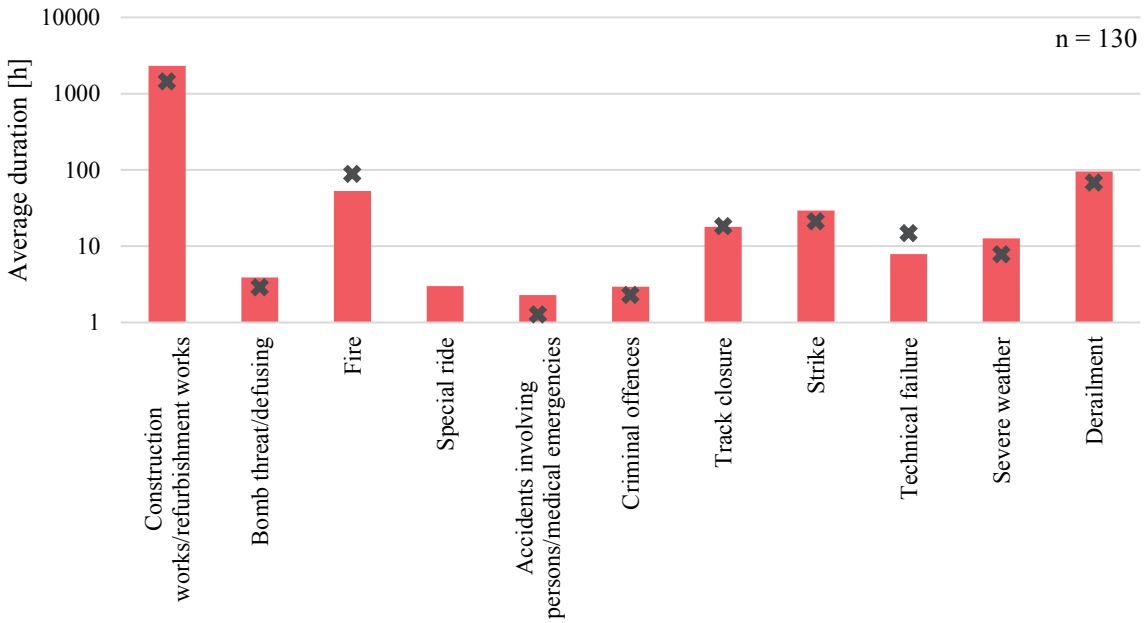

Figure 8. Disturbance duration in average value and standard deviation (black cross) according to scenario category (source: authors)

The database analysis reveals that only a limited number of disturbances events is likely to occur in transportation systems and that these can be typified. Based on the available data (open data as well as data provided by transportation operators), occurrence frequencies for the respective disturbance events can be calculated reliably. This is not possible neither for the duration of disturbances nor for the potential geographical location of any of the disturbance events.

Table 2. Key findings from the database analysis

	Key findings	Comments
Statement 1	A classification or typification of occurrences in railway stations or in railway transportation is possible	-
Statement 2	The frequencies of occurrence of an incident can be determined in a meaningful way	-
Statement 3	It is not possible to meaningfully determine the preferential locations for the occurrence of a particular incident nor its typical duration from the available data.	Improving data quality and spatial resolution, more refined clustering of scenarios

The indications and key findings from the database analysis are summarized in Table 2. It can be stated that the quantitative approach so far has provided a limited number of usable results for the development of process models. Nevertheless, the following section presents an approach to integrate the results of both the qualitative and the quantitative approach into a process model and shows how this is to be used in the future to develop a semi-quantitative evaluation tool.

PROCESS MODELING OF PASSENGER HANDLING

As the above analysis of past events from several different sources shows, only a few incidents can be grasped in a statistically robust manner. The vast majority of occurrences are either too broadly scattered and therefore uncertain, or the statistical coverage is inadequate from the outset. For this reason, past events may not be used directly for the modelling of possible future events. However, they do allow a good estimate of the various developments that may occur. This provides the basis for developing a process model.

In this process model, the process of handling arriving and departing passengers in a railway station is to be modelled in as small steps as reasonably possible. The objective is to identify in particular potentially critical process steps in advance. Thus, potentially critical developments can be identified at an early stage and, if possible,

anticipated before they become effective by means of targeted countermeasures. The modelling is carried out taking into account the results of the expert workshop as well as in close cooperation and coordination with the railway infrastructure and railway operating companies and the other stakeholders.

The modeling is based loosely on the functional resonance analysis methodology (cf. Hollnagel 2012). This technique is particularly suitable for the modeling of complex and interconnected processes, since numerous dependencies of the individual process functions can be mapped. Each function in this process is then examined to see what specific attributes it can have. An example of this is shown in Figure 9 for a small section of the process model. This example shows that the function "Arrival of the train" can either assume the attribute "Premature arrival" if the train arrives before the scheduled time, "Punctual" if the scheduled time of the timetable is met or "Delayed" if the time is exceeded. Similarly, the "Passengers alighting" may be "Hindered" by objects or persons on the platform, or may be "Unhindered". These functions can of course also influence each other. This has to be considered in a later development stage of the model. In the later development stage, the entire handling process from the moment a passenger enters the railway station to departure by train or from arrival by train to leaving the station is to be mapped in this way.

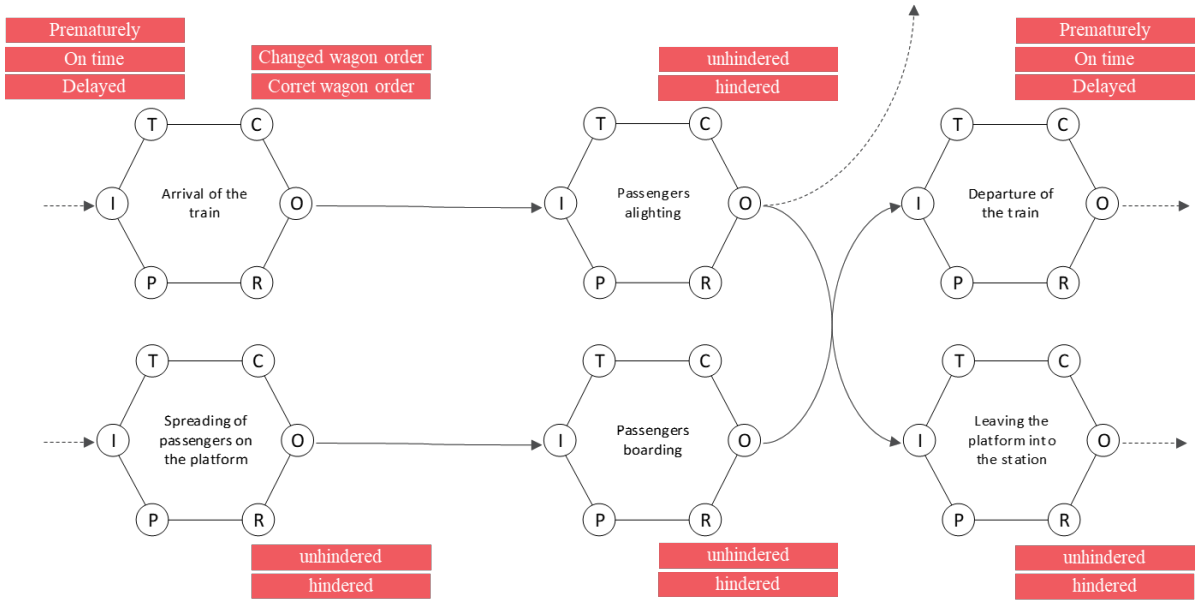

Figure 9. Exemplary process excerpt with the possible attributes of some functions (source: authors)

The process steps and their possible attributes described have to be evaluated concerning their criticality by using qualitative criteria. These criteria must be developed in close consultation with experts from railway operation companies, event organizers and police and non-police public authorities. The intended methodology is based on a methodology developed as part of the RiKoV research project. The RiKoV framework provides a methodology for a scenario-based vulnerability and risk assessment of terrorist threats (Brauner 2017). This methodology will be adapted to the use case of the CroMa project.

RiKoV defines vulnerability through a semi-quantitative assessment that evaluates the effectiveness of preventive security measures in different scenarios and the threat level of the target object. Both these factors subsequently determine the scenario-specific vulnerability of a target. Since this approach has been designed to be applicable to a variety of target objects, it is suitable for application in this research (cf. the application in Gabriel et al. 2018). The system to be assessed can be clearly outlined as an observation space and thus performance, structure, surrounding and time can be assessed with a set of indicators. Each of these indicators can be assessed with an individual score and then add up to a risk classification, which is then classified into one of seven hazard categories with the help of an assessment matrix. In this case category 1 is the highest and category 7 the lowest hazard category, according to the categorization of railway stations by Deutsche Bahn (Brauner et al. 2014).

Within the framework of this project, the above approach is to be adapted. Taking into account the results of the database analysis, the possible attributes of the single process steps shall be made assessable. For this purpose, a score is assigned to each attribute as described above, whereby a high score characterizes an unfavorable or critical attribute. Which attribute and thus which valuation applies to the scenario under consideration is determined by means of a qualitative assessment framework. In this way, a fast and adaptable evaluation by the end user for the respective scenario (e.g. situation, location) should be possible.

By adapting the semi-quantitative evaluation matrix of the RiKoV project, a classification into risk categories will

be possible. On the basis of the process model, a risk indicator should then be calculated for each case under consideration, which in turn provides information on the criticality of the current scenario. The advantage of this approach is above all the consideration of local peculiarities, due to the individual assessability of each process step in the model.

DISCUSSION, CONCLUSION AND OUTLOOK

The active participation in the workshop indicated that there is a high demand for a consistent and preferably verifiable solution on the part of the end users. The workshop revealed some considerable differences between the individual stakeholders involved in the handling of major events involving railway stations. These have to be harmonized and aligned with each other. To this end, the workshop was able to identify the initial prerequisites, but also the boundary conditions and limiting factors in particular.

Database analysis has provided a way of clustering and typifying incidents. Moreover, results for the statistical frequency of certain incidents could be collected. However, it has not yet been possible to extract valid data on the duration or other restrictive conditions of the incidents from the data freely available and provided by the railway operating companies. More data sets will be analyzed in the future with the aim to be able to obtain this information for the definition of the process model.

The approach of the simultaneous or complementary implementation of qualitative and quantitative methods has proven to be of limited use. The workshop provided explorative insights into the topic. Nevertheless, it is disadvantageous that the experts are only able to reflect their individual perceptions and views on the topic. These may be limited and very subjective due to their own experiences and attitudes. However, since this subjectivity should be specifically captured during the workshop, this disadvantage is compensated for.

The quantitative evaluation of databases, on the other hand, only allows for a limited gain in knowledge, since the quality of data, for example on measures taken to mitigate or prevent losses, is often insufficient. Many findings can therefore not be proven statistically sufficient. This could be compensated, for instance, by collecting the data independently, which is also planned within the framework of the project. As a further possibility, the use of probabilistic approaches and simulation models remains.

Modelling of the passenger handling process and the possible attributes for each process function has been started. A probabilistic modelling has proved to be impracticable, as the necessary data could not be obtained from the databases analyzed so far. Instead, a semi-quantitative assessment tool is to be developed in cooperation with the experts and especially end users. With this tool, it should be possible to find critical functions or critical attributes of these. This will provide a tool for end users to make a valid assessment of their own infrastructure against the risk of critical congestion in different scenarios.

Further research is required to this end. An expert panel, which is currently being set up, is required for the ongoing refinement and validation of the process model. Within the scope of this panel, the process model as well as the indicators or attributes and their evaluation are to be checked for plausibility and validated. Finally, it is planned to integrate the tool into a guideline, which will contain recommendations for structural modifications as well as for the management of information and communication between the actors involved.

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