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Impact of notification time on risk mitigation in inland waterway transport

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Purpose: Transport infrastructures form the backbone of today's interconnected real economy. Interruptions in the availability of these critical infrastructures occur, among other things, due to maintenance operations. Since companies and Supply Chains are dependent on planning security, an adequate notification time in advance of such interruptions is required. Otherwise, insufficient notification time limit available mitigation strategies.

Methodology: First, the authors conduct a workshop concept to obtain expert knowledge from stakeholders to identify critical thresholds of notification times, which affect maintenance and logistics operations in inland waterway transport. Second, this research analyses the notification time of closures on an exemplary real-world network of inland navigation.

Findings: The research reveals a high impact of notification times on logistics operations and determines the planning reliability for all parties involved. Data analysis found that the notification time for the majority of the considered closures is below the identified critical threshold. Efficient planning must address this as they pose threat to Supply Chains operations.

Originality: This research is innovative as there is little analysis on inland waterways, even though there exist accessible historical data. This research contributes to this account by linking critical infrastructure, expert knowledge, and supply chain operations. Quantitative methods extend the base of qualitative knowledge gained from interdisciplinary research. Stakeholders can account for notification time in their risk mitigation strategies.

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1 Introduction

Due to the Corona Pandemic, Supply Chain Risk Management (SCRM) receives significant attention in the first half of 2020. Organisations of Supply Chains (SCs) are under pressure "to recognise what needs to be done to assure production at certain levels" (Faertes, 2015). The availability of transport infrastructure is of special interest in the context of SCRM (Li et al., 2016; Hosseini, Ivanov and Dolgui, 2019). Within this context and besides the factors impact, probability, and resilience, another factor comes into focus: risk communication about the enaction and extent of risk mitigation measures by public authorities. In the area of risk communication between the operator and user of infrastructure, the term *notification time* is introduced. Notification time describes the time between the notification from the operator about an impending restriction of a transport way and the actual start of the restriction. For risks that can be identified well before their realisation, stakeholders have enough time to prepare mitigation strategies within this time. This paper introduces the aspect of notification time from the perspective of SCRM and discusses its effect on SCRM strategies.

Notification time concerning events that restrict the navigability and operational readiness of inland waterway transport is the object of study using the example of the West-German canal network. This canal network handles the second most transport volume on inland waterways in Germany following the river Rhine (see Statistisches Bundesamt, 2019). It consists of four canals: the "Wesel-Datteln-Kanal" (WDK), the "Rhein-Herne-Kanal" (RHK), the "Datteln-Hamm-Kanal" (DHK), and the "Dortmund-Ems-Kanal" (DEK). Furthermore, this paper considers two industries that meet their supply primarily through inland waterway transport and depend on the waterway navigability.

1.1 Motivation

Inland waterway transport is an efficient mode of transport to supply large-scale chemical parks, power stations and to transport bulk goods. It provides capabilities for the handling of certain dangerous and bulky goods (like a gas turbine with a weight of 600t). Albeit industries depend on the navigability of the waterways, which is not continuously given: the chemical company BASF SE lost over EUR 245 million during the river Rhine's low water tides in 2018 because the supply by inland waterway transport became disrupted (BASF SE, 2019; Reuters, 2019). The port in Marl, among other ports, could not be accessed for almost two weeks due to ice-coverage of the canal "DHK" in February 2012, inducing significant loss of production capacities to the connected chemical industry park (see ELWIS-database, 2019; Workshops, 2019/2020).

The examples above highlight the dependency of specific SCs on the availability of inland waterways. SC disruptions can propagate downstream of the disrupted SC resulting in risk consequences for additional companies, too (Merz et al., 2009). These consequences are particularly relevant in the case of the (petro-)chemical industry as its products are plentiful and used across industries. For example, a disruption at the chemical park mentioned above caused a shortage of a necessary component for the global automotive industry in 2012. Therefore Yan et al. (2015) identify this park as a highly relevant supplier hidden in various multi-tier SCs due to the global effects of the local disruption.

Furthermore, in the field of risk and disaster management, mitigation, prevention and preparedness as part of the pre-disaster phase are highly relevant (Coetzee and van Niekerk, 2012). Therefore, timely and effective early warnings can enable powerful measures and promote the need to identify early warning times (Todd and Todd, 2011). In the considered field of infrastructure failures, this aspect is about time to prepare for disruptions in SCs, such as those caused by scheduled and notified maintenance closures. A prominent example is the port of Dortmund, which could not be accessed by waterway for six weeks in 2019 and will not be again for six weeks in 2020 due to a lock which is permanently under maintenance (ELWIS-database, 2019)

1.2 Research Objective

This paper aims to investigate the relationship between notification time about restrictions to inland waterway navigability as an enabler for industries to deploy risk mitigation measures. The waterway authority (WSV) announces the restrictions which are targeted to shippers. This allows industries to reorganise their transports, which requires preparation time and enhances the effectiveness of available mitigation strategies to alleviate the effects of the restriction on their affected SCs if necessary. This relationship has not been examined in literature so far.

Assessing the impact of the notification time to SCRM due to restrictions of transport infrastructure is complex because the impact depends on available risk mitigation strategies at the current state of the SC (Tomlin, 2006). Therefore, a mixed-methods approach is suitable. This paper investigates the effects using an exemplary real-world network by obtaining expert knowledge of stakeholders involved in operating the infrastructure. Furthermore, experts of industries are stakeholders who participated in held workshops. The acquired expert knowledge is then compared with the historical notifications about restrictions in the canal system with means of data collection and analysis. This approach allows the authors to draw conclusions about the preparation time of mitigation strategies and to derive an estimate about how logistics operations become affected by the notification time.

Overall, the paper aims to answers the question of what an appropriate level of notification time is. The criterion for this is the possible implementation of measures to ensure SC operations against the risk of infrastructure unavailability. Moreover, this paper defines the critical threshold of notification times at which stakeholders can deploy further mitigation strategies for the unfolding disruptions.

1.2.1 Outline

This paper addresses the research question in five sections as follows: First, this paper maps the relevance of notification time into the concepts of risk management and SCRM, thereby describing related and existing works to introduce the topic. Then, the paper establishes its mixed-methodology by setting up the workshop concept firstly. Secondly, the findings of the workshop regarding notification time and their consequences for SC operations are compared to the found situation in the West-German canal system by analysing data of the issued notifications from the authorities. In the following two sections, the paper presents and discusses the obtained results. Finally, the authors link the results to the perspective of SCRM and outline further research steps.

1.2.2 Definition

The scientific literature rarely takes into account the discussed notification times. Similar aspects are regarded within the field of disaster management, for example as part of early warning systems. There, the term warning time is more present and is related to the fact that short warning times do not allow effective measures, concerning disasters like natural hazards, to "be implemented in the time available for preventive action and are, therefore, very critical" (Krausmann et al., 2011). To distinguish large-scale disasters from the interruptions considered here, the authors speak of notification times within the research scope. This term transfers the warning time and concepts of disaster management research to the field of SCRM.

2 Literature Review

The dependencies between SCRM, underlying transport infrastructure and risk management are investigated in their respective areas of research. The following section first briefly outlines these interdisciplinary approaches before the concept of notification time is classified from disaster management approaches.

2.1 Supply Chains and Inland Waterway Transport

Inland waterway transport explicitly in the scope of Supply Chain Management (SCM) is considered in one paper (Achmadi, Nur and Rahmadhon, 2018) and one dissertation (Caris, 2011). Pant, Barker and Landers (2015) quantify the consequences of disruptions of inland waterway ports serving multiple industries with waterway connections to multiple regions by calculating the economic losses of industries. More often, the direct risk associated with navigation of inland cargo vessels is analysed (i.e., Xin et al., 2019; Zhang et al., 2014; Yang, Xing and Shi, 2020). Since the literature on waterway transport seldomly considers the supply chain management perspective and does not consider warning or notification times of possible disruptions, the following two sections elaborate on these aspects.

2.2 Supply Chain Risk Management

Risk management is becoming increasingly important in the area of SCM. SC Risk Management (SCRM) is identified as necessary for the agility and robustness of a company and is gaining importance with increasing risks (Wieland and Wallenburg, 2012). Since a SC comprises companies that want to improve their efficiency and effectiveness by integrating and coordinating the flows of materials, goods, information, knowledge and finance, efficient risk management is of need (Bowersox, 2013). This need reflects risks from SC disruptions, which can be neglected by focussing primarily on cost reductions (Khan et al., 2008).

Tomlin (2006) identifies the significance of mitigation strategies for managing SC disruption risks. Therefore, several research attempts deal with the robustness of SCs (Hosseini et al., 2019; Shukla et al., 2011) as well as with the direct analysis of disruptive effects in SCs (Käki et al., 2015; Kleindorfer and Saad, 2005; Sawik, 2019). Further attempts investigate SC robustness and disruption risks in SCs on the background of a natural disaster (Fujimoto, 2011; Park et al., 2013). Whereas most of this research is focusing on the topology of the SC like single or multi-sourcing structures (Yu et al., 2009), Hosseini and Barker (2016) also analyse timely effects which lead to the resilience of infrastructures. In the latter case, the timely effects are limited to the time after a disruption occurs and therefore does not consider the time before it occurs. The following section examines time aspects of the pre-disaster phase from disaster management. The concept of notification time is associated with early warning systems, which are also becoming increasingly important in SCs.

Referring to early warning systems, the connection between what is particularly present in the area of natural disasters and the briefly discussed SCRM does not seem that obvious at first sight. Nevertheless, few early warning systems are currently present in SCs. They aim at identifying negative trends or operational risks for SCs as early as possible to prevent a reduction in sales, damage or even bankruptcy. Therefore, both qualitative and quantitative methods can be used, for example, for long-term forecasts of structural changes, with the crucial question being how much time is lost until the measures become effective (Romeike and Brink, 2006).

2.3 Notification time in risk management

The field of risk management uses disaster management cycles to explain and manage the impacts of disasters (e.g. Baird, 1975; Coetzee and van Niekerk, 2012; Khan et al., 2008). Their three key stages are namely the pre-disaster phase, the disaster occurrence and the post-disaster phase. They comprise all activities, programmes and measures aimed at preventing a disaster, reducing its impact or recovering from its losses (Khan et al., 2008). Apart from this, many attempts of more precise disaster management cycles exist, in which, partly due to the various characteristics of disasters, the phases may overlap and be hard to distinguish (Neal, 1997). As an example, figure 1 depicts an early attempt.

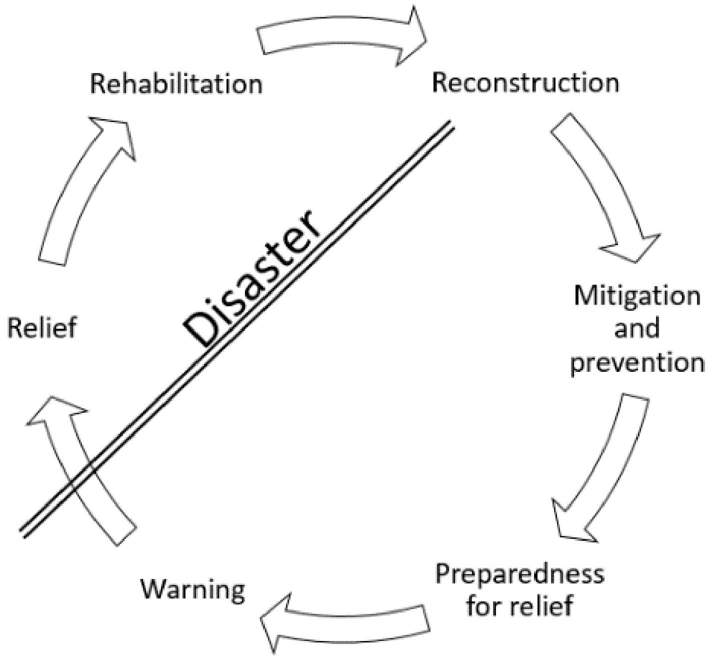

Figure 1: Disaster management cycle (adapted from Baird, 1975)

The pre-disaster phase is significant since it deals with the predictability of the occurrence of disasters. This mostly includes their unpredictable and precise location, timing, or severity and can include measures like plans for timely and effective early warnings (Todd and Todd, 2011). As phases that need to be considered before the occurrence of a disaster, figure 1 shows the aspects of mitigation, prevention, and preparedness as part of the pre-disaster phase (Coetzee and van Niekerk, 2012). Moreover, the cycle shows a phase of warning, which should be taken into account in the management of disasters (Baird, 1975).

In summary, the research about SCRM mostly neglects the aspect of warning times or notification times, which is why the concept of disaster management is predominantly used instead. The source knowledge from primary literature has to be extended to connect these concepts through the defined notification time and be able to elaborate on the impact of notification time on SC operations.

3 Methodology

Expert knowledge is necessary to assess the minimum level as a critical threshold of notification times for inland waterway transport as there are no concepts in SCM about it. However, they may be subject to cognitive or motivational bias, which must be addressed by the concept and methods of gaining reliable expert knowledge (Miles, Huberman and Saldaña, 2014). These insights from the contributory expertise of the experts can be linked-to in the analysis of empirical data from historical disruptions. This also diminishes the potential bias of the experts due to a quantitative methodology. The workshop and the data analysis together form the mixed-methodology of this paper.

3.1 Workshop

Expert knowledge has to be extracted and used to identify appropriate levels of notification time and to be able to deploy SCRM mitigation strategies in case of infrastructure restrictions. Therefore, an interdisciplinary workshop concept is developed by considering an interdisciplinary workshop as an openly structured working meeting with participants from different disciplines, in which different questions can be worked on together by using appropriate techniques (Niederberger and Wassermann, 2015).

The development of the workshop concept must meet certain conditions to benefit from interdisciplinary workshops. These conditions concern, among others, a suitable location and a positive working atmosphere as well as a clear definition of the topic or objective. The composition of the participants also plays an essential role since it influences the arrangement of the points mentioned above (Beermann et al., 2015; Lipp and Will, 2008). One aim was to identify appropriate notification times for infrastructures and, to be suitable for causal research, identify their dependency on reasons for the infrastructure closure. Expert interviews within the held workshop should allow identifying critical thresholds of notification times, which affect maintenance and logistics operations.

Two separate workshops took place ten months apart. The contributions regarding the mentioned sub-target took about half a day each. Six invited participants from all relevant stakeholders attended both workshops; this includes experts from public authorities, science and industry. The groups of participants overlapped but were not identical.

The first workshop served to identify predominantly qualitative correlations. Through open discussions and group work, insights could be gained and manifested, which are essential for the risk assessment of the infrastructures under consideration, including the need to examine the question of appropriate notification times. Interactive discussions and an attempt at gamification were developed and applied to address the risk assessment within the second workshop. In particular, the approach of gamification could manifest insights into the possible mitigation measures that differ in the perspectives of the stakeholders.

Overall, open discussions contributed to identifying essential relationships and processes. Subsequently, the experts were confronted with scenarios and conclusions based on these, which could be falsified, validated, or extended by the methods used in the workshop.

3.2 Data Analysis

In addition to the workshops, this research elaborates on the relation of the notification time by conducting data analysis about the situation in inland waterway transport. This contributes quantitative insights into the qualitative relationships obtained by the experts.

The notification time for restrictions to inland waterway transport is determined by an analysis of 'Notifications to Skippers', which is in the following abbreviated as NtS, which are issued by the WSV and are accessible online (ELWIS-database, 2019). NtS are usually targeted to all vessels at the waterway and inform about changes of valid regulations or navigational charts. They also contain temporary directives from the WSV or shipping police that affect navigability and thus are of interest.

NtS contain information about the issuing instance, the date of issuing, the date of validity and date of expiry. Also, the variable *interval* indicates whether the restriction is valid throughout or only at particular time intervals of a day. The data includes the *types of restriction* to navigability, the *affected group* and states a *reason*. Furthermore, a NtS refers to an affected waterway *infrastructure object* and its *waterway*. This enables the analysis of the *notification time* in which stakeholders can reorganise scheduled transports. Moreover, NtS contain further information, which allows data drill-downs, like the mean of communication, the range of restriction, the reporting obligation, version number, the issuing instance, and additional information provided by the issuing instance.

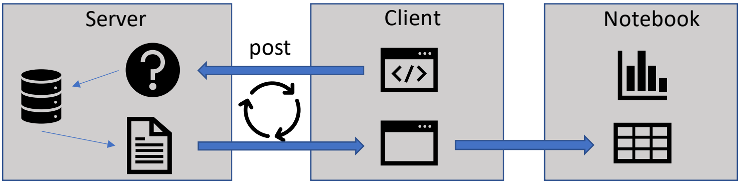

Figure 2: Schema of the data collection process

Figure 2 depicts the whole process: The authors collected the NtS individually through the ELWIS-web interface with the python-requests module by using a post-request to the "ELWIS"-*server* which returns the NtS-document from the database. The document is then fragmented into data entries that are transformed to variables at the *client*-side with python. The created record has a uniform syntax on the *client*-side that is appended to the dataset. The dataset is indexed by the ID of the NtS as well as the locations the NtS refers to. The analysis is then performed on this dataset using a jupyter®-notebook.

The database contains scattered NtS since 2001, albeit continuously since 2007. Overall, the dataset contains 47,425 records and 27 variables. As one NtS-ID can refer to multiple locations, the unique number of NtS totals 39,964. In a first step, only the NtS for the waterways of the West-German canal system is used, dropping the number of records to 3,838.
The records contain information described above and further details separated into the record variables shown in figure 3. Most NtS contain a field for *additional information* specifying the notifications or instructions given

by the waterway authorities. The dataset is mostly complete, as seen in figure 3: Collected data are depicted in dark grey, whereas missing values in the dataset are depicted in white (design by Bilogur, 2018).
Missing information could be completed with further assumptions, which

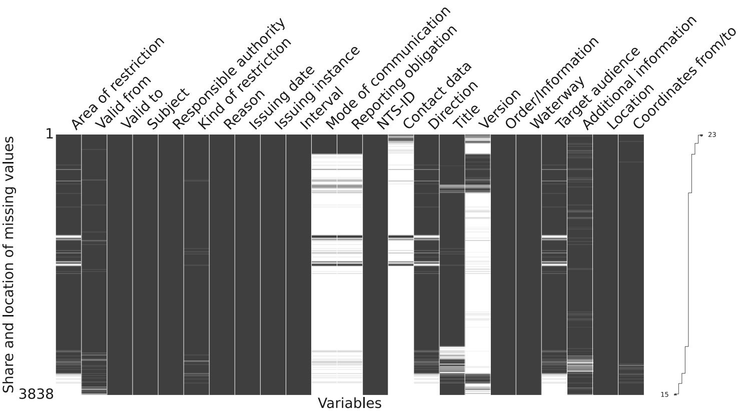

Figure 3: Overview of variables and completeness of the dataset

are backed up by the expert knowledge gained from the workshops discussed in section 3.1. These are namely the following: The NtS are published as notifications with implication on inland waterway transport and not for informational purposes only, which were dropped before. A missing value of the variable *version* indicates NtS without further changes to the notification issued by the authority, meaning a version number of 1. If not otherwise stated, the NtS are released by radio (the value is "UKW"). If not otherwise stated in the column *Interval*, the NtS are valid continuously from the starting date (*Valid from*) until the date of expiry (*Valid to*). Twenty-seven records were deemed not relevant.

NtS purely being issued as an informational note or NtS that were being revoked by the WSV are also dropped. This is indicated either in the title or is identified by value mapping and analysis of the types of restrictions. This eventually drops the relevant dataset to 3,332 records. The distribution of the counts of records for the waterways in the West-German canal network over the years is shown in figure 4. Not many NtS were issued for the DHK, and there are differences in the number of records across the years. The periodicity of records seems to correlate indicating relationships between the canals. The composition of the findings is stated in section 4.2.

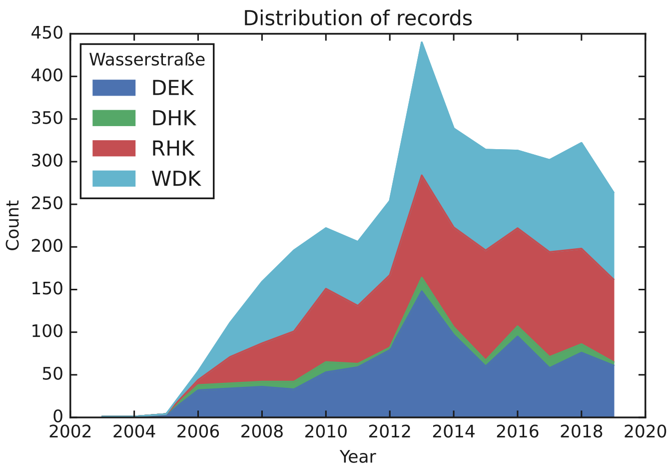

Figure 4: Distribution of NtS records (ELWIS)

4 Findings

By using the described mixed-methods approach, several findings could be extracted and validated with different approaches. In the following, the mostly qualitative results of the workshop are highlighted first. Then, the results of the data analysis are presented.

4.1 Workshop

The findings of the workshops are referenced to by Workshop I (2019) and Workshop II (2020). One of the findings of the workshop implementation was that the possibilities of the industry as a stakeholder are limited and dependent heavily on the notification time. This is partly due to a bottleneck in the transport capacity of alternative modes of transport. Another restricting factor is the storage capacity, which varies for industries. Therefore, the possible stock level and production capacity are identified as further limitation factors. Since those identified limitation factors are finite physical values, they are assumed as fixed values for the analysis of the parameter notification time.
Given those fixed values, an average required minimum notification time of two weeks could be identified, as this is likely to enable the procurement of capacities of rail cargo transport. The consequences of long-term disruptions with a notification period of less than this critical threshold contain significant impacts on businesses in the industry surveyed, which is highly dependent on the functioning of inland waterways. This includes supply bottlenecks up to a complete stop of production. The latter is particularly

critical if the industry concerned is part of critical infrastructures such as public utilities.

No significant pressure in logistics operations is given if the notification time is more than 28 days. This applies to short-term and average restrictions. Whereby restrictions that are in effect for less than a day are considered *short-term,* and average restrictions are manageable by SC operations since valid risk mitigation strategies can still be deployed in time.

The definition of the duration of average restriction differ between industries and business because their SCs have different vulnerabilities to infrastructure closures. Power plants have large storage ranges of up to months so that an early notification time allows for adjusted stockpiling and production planning. Also, road cargo is a possible, albeit costly option. This is not the case for the chemical industry: The storage ranges are within days, and storage is used by both supply and finished products. Hence, this industry needs to maintain a minimum level of access to inland waterway transport during times of temporary restrictions. The information about the interval of the restriction is found in the NtS. Early notification allows for scheduling daily logistics operations more easily to the unrestricted intervals. The strategy of restriction intervals to allow a minimum level of navigability is utilised by the WSV.

The mixed-methods approach shows that some of the restrictions have less relevance for inland waterway transport, like closures due to special caution. However, the workshops revealed that even minor delays of less than one hour potentially stack up because the unloading crew at a port might not be able to clear cargo this day anymore, which leads to further delays. Further findings from the workshops reveal that the direct effects of weather are neglectable in waterway canals. Thus, the limiting factor of inland waterway transport through the canal network are the restrictions communicated by the waterway authorities.

4.2 Data Analysis

The data analysis of the NtS that are communicated by the waterway authorities supports the aforementioned findings: The duration of most restrictions is less than a day and therefore, still provides timeframes for navigability. The types of restriction and their average notification, as well as the duration of closures, are reported for the 3,332 NtS in table 1. It is depicted that the reported mean of notification times for closures is about 22 days and meets the two-week threshold but not the 28 days. However, the median is way below (7 days), suggesting that logistics operations become affected even more (see 4.1). The variable *Time to repair* indicates how long the restriction remains. Further findings are outlined in the figures below.

Table 1: Restrictions of the West-German canal system

		Notification time [d]		Time to repair [d]	
Restriction	Count	mean	Me-dian	mean	me-dian
Closure	1781	22.08	7.0	6.39	0.0
Special caution	535	17.26	4.0	17.23	1.0
Partial closure	369	13.41	5.0	8.16	0.0

		Notification time [d]		Time to repair [d]	
Restriction	Count	mean	Median	mean	median
One-way only	198	14.02	4.0	59.56	6.0
Restrictions	117	2.50	3.0	5.72	1.0
Operations restricted	78	3.26	0.0	49.67	2.0
Docking ban	71	19.22	3.0	16.9	3.0
Maximum Ship length/width	62	32.40	10.5	80.25	8.0
Delays	49	14.86	6.0	28.94	1.0
Operations changed	46	0.13	0.0	295.3	1.0
Operations closed	26	15.19	5.0	7.77	1.0

The availability of inland waterway transport is mainly dependent on the locks and the canals itself which 2,909 records refer to. The statistics of their respective notification times are depicted in the violin graphs in figure 5

and figure 6, which are scaled by the count of records for each category at the x-axis (Design by Waskom et al., 2017).
The blue-coloured violins represent the records where the *Time to repair* [TTR] was less than a day; the brown-coloured violins depict the remaining records. Figure 5 illustrates that the median notification time for closures is about eight days and that 50% of observed values are between zero and 24 days. For closures that last for longer than a day, the average notification time is 25 days. The average notification time for full and partial closures lasting less than a day is significantly lower. This relationship between the medians (white dots) and averages (the middle of the black box of the interquartile ranges) is opposite to the category "Special caution" and the other types of restrictions. This opposite relationship is also partly true for the distribution bandwidth (less kurtosis of the brown-coloured violin for the former categories, significantly more for the latter categories). Furthermore, closures due to special cautions and other reasons have much lower notification days of just about four days. The category "other" in figure 5 mainly features "one-way-only" directives and rather unspecified restrictions as pictured in table 1 above.
Differences exist between the records according to the *reason of restriction*, which is emphasised in the scaled violin plot in figure 6. Figure 6 examines the full closures lasting longer than a day. Here, the interruptions mainly occur due to repairments, which have a shorter average notification time than maintenance operations or scheduled events. The category "other" in figure 6 mainly features inspections and construction operations.

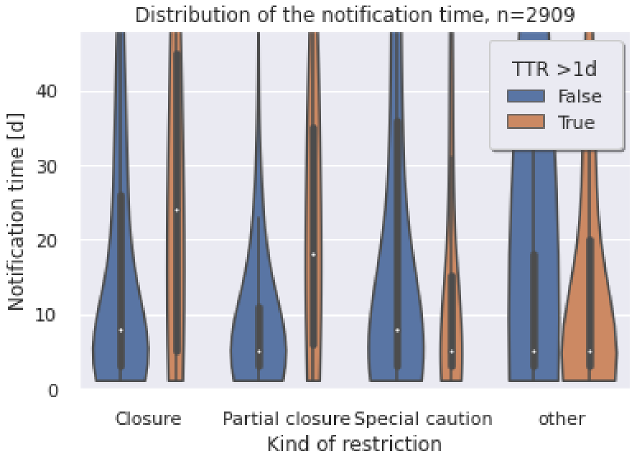

Figure 5: Distribution of the notification time regarding the type of restriction

Figure 6: Distribution of notification time regarding the reason for restriction

Surprisingly, the sound assumption that a longer *Time to repair* would be notified more in advance could not be met based on the underlying data. Even though relationship tests, which included correlation and hypothesis testing, were conducted between the variables *Notification time* and *Time to repair*, the results show no significance for the entire time scale. This is explained, at least partially, by the large variance of closure times caused by accidents which required repairs lasting over a year. Accidents understandably have a notification time of zero, whereas most disruptions of the waterway infrastructure with varying notification times were fixed within hours.

5 Discussion

The presented research outlines an innovative approach to analyse notification time and impact on logistics, which is rarely considered in the literature so far. Whereas expert knowledge within a targeted workshop concept led to findings of processes, industries and mitigation measures, the analysis of historical data could deepen the overall analysis by contributing quantitative findings referring to the notification time. Further relationships between the infrastructure restrictions, the fixing infrastructure operators, and affected industries, show the significance of respecting possible notification times.

The mixed-methods approach reveals that some of the restrictions have less relevance for inland waterway transport, like closures due to special caution. Furthermore, ships in the West-German canal system often drive a roundabout to the seaports, which limits the possibility of earlier procurement, as transport capacities are in transit.

Limitations of the presented research exist primarily in the dependence on the data quality, which regards to both applied methods. Since the quality of the expert knowledge collected in the workshops depends on many factors like personal involvement, these must be considered in order to obtain usable data quality. Furthermore, the data quality and accessibility have a big influence on the results, as well as the quality of assumptions met to complete the incomplete records. These issues were accounted for in the data processing steps and lead, among others, to a reduced number of observations. Overall, it can be stated that the data situation for this conducted research is solid.

All potential sources of interference that could affect the implementation and evaluation of the workshop concept were considered. Moreover, further implications of the extracted expert knowledge supported the data analysis to be able to summarize the types of restrictions to the categories depicted in figure 5 and figure 6.

6 Conclusion

The research reveals a high impact of the notification time on logistics operations in inland waterway transport and reveals the planning reliability for all parties involved. Restrictions that heavily affect navigability, closures, are either tried to be limited to hours at a day or notified in advance. The mixed-methods approach found that the notification time for most of the short-term partial and full closures is below the identified critical threshold. As these pose threats to SC operations, SC planning must account for these restrictions.

This research is innovative as there is little analysis on inland waterway transport as outlined in section 2.1, even though accessible historical data exists, and inland waterway transport is crucial for the chemical and energy industry covered above. This research contributes to the literature by linking critical infrastructure, expert knowledge, and SC operations. Quantitative methods provide the base of broad possibilities for interdisciplinary research. Furthermore, the presented analyses can be used to support SC and infrastructure monitoring processes to account for different risk mitigation strategies depending on the notification time.

Further research could integrate the notification time in the anticipation stage of the concept of SC resilience, as the two concepts are related like the disaster management cycle in figure 1 suggests. SC resilience covers the time aspect concerning *recovery time* already. Also, further research could investigate changes in SC operations due to notification time or the restrictions itself by data analysis of inland AIS-data, which tracks ship movements.

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