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Infrastructural, Decisional and Organizational Aspects to Use Mode Shift to Handle Disruptions in Freight Transport: Literature and Expert Survey

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ABSTRACT Freight transport disruptions in recent years caused production shutdowns in the industry, supply shortages and high economic damage around the world. In practice, contingency strategies from transport operators are often weak and disruption management fails to handle the situation sufficiently. Despite availability of data collection, academic optimization approaches, and multiple initiatives for coordinated multimodal management in case of disruptions, there are multiple infrastructural, decisional and organizational issues, which limit their applicability. We study those factors by a literature analysis, and a survey in which we ask practitioners, authorities and academic experts to discuss specific aspect in structured and unstructured form. We summarize some parameters, which can be influenced by strategic, tactical, operational actions, and those others referring to systemic properties; or disruption characteristics, which can only be hedged against. Hereby, we offer a knowledge base to future projects aiming to optimize multimodal management at strategic tactical and operational scope, to counter disruptions in freight transport networks.

INDEX TERMS Multimodality, disruptions, freight, survey.

I. INTRODUCTION

THE DAILY costs of transport disruptions caused by delays or complete cancelations can be massive. We refer to severe unexpected disruptions causing strong negative impacts (limited, or no possibility to use some facility or link), large exposure (large volume of freight affected), for a longer amount of time (more than a day) on the freight transport system which require considerable response activities by transport operators and affected companies. Minimizing the threat or impacts of such disruptions is a crucial field of action for actors involved in freight transportation. In the transportation context, we refer to several possible scenarios being considered disruptions. These include the closure of a railway or motorway link because of natural disaster damage; the inoperability of an intermodal terminal, or a transport link, because of staff shortages; infrastructure breakdowns due to lack of maintenance or inoperability of transport units because of environmental conditions (see for example [1]).

Such disruptions can have large effects to freight transport. For instance the Rastatt disruption mentioned in [2] is reported in [3] to have caused more than 12 million euros losses per week to freight companies, requiring diversion of more than 200 freight trains per day, for a period of 2 months. Smaller disruptions are frequent; disruptions are variable in duration, scope, impact, costs; those are often undisclosed for competitive reasons.

Disruptions can be managed at three different stages. Prior to its occurrence, i.e., in a strategic point of view, mitigation of exposure or impact is sought. During its occurrence, at a tactical and operational scope, the impact of the disruption is minimized by means of contingency plans. Finally, after the disruption, actions aim at restoring full system functionality and analyze best practices. The usage of multiple modes can help throughout those three phases; there have

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been multiple mathematical models able to deal with specific aspects (in undisrupted case, see [4]).

The implementation of those approaches is limited by available infrastructure; data and decision support systems; process and organizational aspects. The identification and analysis of them represents the focus of the present work. The paper builds some background in Section II, presents methodology and contribution in Section III and discusses state of the art and the surveys in Sections IV and V, respectively. Section VI concludes the paper, and draws a closer link with ongoing trends in transportation and logistics.

II. BACKGROUND

Disruptions of freight transport systems can have multiple different forms, causes and severities; affecting node (a terminal, origin or destination), link (railway lines, motorways or inland waterways) and/or network (affecting multiple links/nodes) [5]. Depending on the severity of the disruption, nodes and links can be completely inoperative or operate on lower capacity than without the impact of the disruption. Based on the classification by [6] response activities can be categorized as strategic (long term), tactical (medium term, also including during long disruptions) and operational (affecting already running services, rescheduling/reassigning resources or routes). Mode shift has requirements at all three levels.

One strategy of responding to disruptions is employing alternative transport modes for shipments [7]. Thereby goods are transported by another mode than usually planned from origin to destination on the complete length or just on certain sections, for example to bypass a closed rail corridor. A specific disruption can affect at various levels some modes, or mode interchange facilities, more than others, thus identifying mode shift as a possible solution to disruption.

Overall, the usage of multiple modes defines the concept of mode shift, which also relates to multi- or intermodality. In unimodal freight transport, only one mode is used; multimodal freight transport describes transport chains wherein at least two modes are utilized to ship the goods from origin to destination [8]. Intermodal freight transport is a special form of multimodal freight transport, because the goods are moved on the entire journey in the same loading unit or road vehicle which is transported by different modes. The goods themselves are not handled when changing mode [8]. A common example for intermodal freight transport is container traffic. Mode shift in this study includes all of the above, plus switching from unimodal transportation on one mode to unimodal transportation on another mode, as well as switching from a unimodal transportation to a multimodal or intermodal transportation and vice versa.

We also discuss briefly the concept of synchromodality, considered as an adaptive mode choice based on real-time information about the multi- or intermodal freight transport network [9]. Other authors consider it extending more in the supply chain and include multiple transportation links as well as inventory management [10]. Much research on synchromodal solutions assumes full flexibility in switching modes before operations [11], or during operations as situations are identified [12], information availability, and extensive collaboration among the stakeholders. Under this assumption, researchers are mostly working on optimization models; or integration platforms, to estimate the potential of such dynamic mode shift. Serious games approaches have been also used to probe and convince stakeholders of the potential of synchromodal principles, and information sharing.

While synchromodality inherently solves aspects such as short frequent variations of travel time, link capacity, node capacity, perishability of the commodity, the discussion of its performance in disruption received attention only later [13], [14]. In any case, as synchromodality inherently considers change of mode if circumstances suggest, it does not include an (unexpected/unplanned) change from a unimodal freight to another unimodal transportation scheme or to a multimodal strategy in response to disruptions [15]. In other terms, having a functional synchromodal implementation will have addressed most of the organizational, infrastructural, and decisional issues discussed in the present paper. We remark anyway that the academic literature on synchromodality does not discuss in detail the practical relevance of those organizational infrastructural and information aspects, which might be required to implement synchromodality. We identify the largest factors for acceptance of the synchromodal paradigm to readiness of the operators and companies for mode shift, legal aspects and sometimes also capacity or cost constraints. Similarly, [15] generically speaks of acceptance of planning flexibility by the stakeholders.

III. CONTRIBUTION AND METHODOLOGY

The present paper investigates the possibility of using mode shift (using multiple transport modes; shifting from one given transport mode to any other possible transport mode) to manage disruptions in freight transport networks. Much ongoing research focuses on optimization approaches (which decision to take when?), and software platforms/tools/frameworks involving stakeholders (which digital tools enable to take which decision? what is its potential?).

We tackle the complementary research question of studying the infrastructural, decisional, and organizational aspects (barriers; and possible solutions: why this theoretical solution might not work in practice?) for the implementation of mode shift, to counter freight transport disruptions. We look for practical organization, infrastructural and decisional aspects, i.e., barriers, which affect the potential of modern data collection and processing, optimization and decision support; and possible solutions to those barriers.

The key issue in using mode shift, is to which extent the various stakeholders, based on the existing processes, infrastructural resources and decision making possibilities, are (1) willing to accept the delay cost of waiting until the disruption is resolved; (2) willing and able to find an alternative route within the same mode, which avoids the disruption, with typically some extra delay or extra cost; and/or (3) willing and able to find an alternative mode which allows the shipment of the goods, with some possible delay, and a cost for mode shift.

Those questions touch upon very practical aspects, related to organization (who is in charge of doing what when? Based on what information, which constraints, and which goals?), decisional (what information is available when? In which format? How reliable/trustworthy is it?) and infrastructural aspects (which infrastructure is available, in normal and disrupted conditions? what is its precise performance in terms of flow, capacity, and speed?). All those aspects are complementary to the availability of optimization and control tools for freight transport networks, which have been much more studied in the literature (see for instance [4], [16]).

To answer this research question, we review the state of the art, and use expert surveys. In the literature, many studies model transport systems and analyze how the modeled transport units would react to disruptions or natural disasters when imposed to different constraints. Fewer studies are able to monitor a system during a disruption, or study its performance post-eventum, as not all available data or reasons to justify the decisions taken might be available. As [17] note, disruptions "are often the result of some totally unexpected mechanism and there are therefore virtually no empirical data about their frequencies and consequences".

We tackle the shortcomings of the existing academic studies by an empirical analysis utilizing semi-structured expert interviews with differing views on the transport system. This approach has been used already in the literature [1], [18] for studying practical aspects of transport disruptions.

IV. REVIEW OF THE STATE OF THE ART

The studies of disruptions identify using multiple modes as generally beneficial, despite many studies suffer from several limitations (see for example [7], [10], [19], [20]). A standard procedure for determining relevant articles, plus snowballing references from them, resulted in the works presented in Table 1. The organized summary of the papers reviewed describes the categories of type of disruption studied; consideration of mode shift; and specific requirements identified (column 2-4 respectively). We here discuss the most relevant concepts. All investigated articles agree that mode shift as a response to disruptions in the multimodal transport system is beneficial in terms of delay reduction as well as cost reduction when considering supply chain disruption costs and delay costs. Investigation of response in past events is rare (see for example [1], [18]).

Optimization implies low redundancy; second best option is worse. From a network perspective, transport systems of different modes might, especially during disruptions, be complementary to each other. Single mode systems (roads excluded) often do not have many redundancies because they reduce the efficiency of the system by increasing costs. Those redundant facilities will not be strictly necessary under normal operation. Most current transport systems are efficiently designed because they are in competition with each other; therefore, overcapacities are rare; and the second best option has typically a much larger cost than the optimal one. Multiple different complementary and interconnected transport systems effectively determine alternatives for freight transportation if infrastructure and service access are available [21]. The complementary systems act as a virtual redundant system, if shifting mode is possible (see [19], [22], [23]). Most often, the compensation of the capacity in a mode cannot be complete, though. True redundancies in the whole system are still necessary to mitigate the consequences of disruptions [18], [22].

Mode shift requires accessibility by multiple modes: The study [24] on the supply network of coal power plants finds that facilities with active access to multiple modes of transport are better positioned if disruptions in one mode occur. Some mines for example can shift coal supplies from rail to road but some power plants do not have the possibility to unload trucks. While the network infrastructure is available at least on a larger geographical level in North America [7], [20], Europe [13], [22], and China [21], on a smaller geographical level redundant transport systems are often not available and mode shift strategies are not applicable (see for example a study from Norway [25]).

Costs for delay must be balanced against cost for mode shift: Since mode shift always includes additional handling of goods and in most cases also switching to a less efficient mode for that particular good, it can be much more expensive than the planned transport chain not considering the disruption [24]–[26]. This implies that (1) transport operators might favor waiting if they are not incentivized by delay penalties to take action [26], [27]; (2) costs for switching to another less efficient mode can be so high, that waiting to a certain extent is less costly than taking action even if considering potential production losses which is especially the case for bulky goods transported by barge [25], [28], [29]; and that (3) progressively taking action when a disruption occurs might not be worth it, if it is quickly fixed [13]. Hence, trading off the costs of waiting and mode shifting is necessary. Properly calculating this trade-off therefore requires a transparent, trustworthy and reliable estimate of the disruption duration [13]. This is a well recognized issue in the dynamic setting of a disruption, where cooperative behavior of the stakeholders is often assumed necessary.

Handling costs limit mode shift; road transport has higher redundancy. Studies find that shipments which were planned to be transported by road do not switch to another mode even if the road transport network is disrupted on a certain link [28]. This is caused by wish to avoid the previously mentioned handling cost, with the high redundancy of the road or specifically the motorway network. It is cheaper to reroute trucks instead of investing in additional handling because different routes are nearly always available, and detours are relatively small [28]. This stresses the importance and advantages of mode shift in scarce networkswith fewer redundancies, like the railways or inland waterways [18], [19], [22], [24].

TABLE 1. Literature review on mode shift in disruption response.

Article	Disruption	Findings on mode shift actions	Requirements for mode shift
[1]	Rail network, multiple disruptions	Operators and infrastructure managers unprepared No a priori preparedness and crisis management measures and skills available Lack of backup systems in single modes Rail operators were not able to organize mode shift on themselves Shippers, forwarders and integrators shifted deliveries from rail to road	Additional personnel are readily available. Crisis management plan and a priori determined measures available
[18]	Rail, long term	Schedules for domestic intermodal services lengthened; original wagon rotation not feasible; Change to diesel-locomotives for route change necessary Response to closure improved over time Fragmented rail freight operator market imposes resource challenges Intermodal terminals have less time for handling trains; few alternative routes logistic providers in domestic intermodal traffic can switch urgent shipments to road Some intermodal shipments switched from rail to short sea	Contingency plan on strategic and operational level available and continuously updated especially for intermodal services
[24]	inland water way, coal transport	Coal power plants and mines rely on one mode (i.e. inland waterway shipping), no rail access, truck capacity too small; physical absence of alternatives Mode shift choices are related to other logistics costs (loading, unloading, storage) Access to multiple modes reduces impact of single-mode disruptions	
[25]	Closures of rail lines in intermodal network	Dynamic mode shifting to barge or truck gives best distance, cost, lead time performance For some orders it is cheaper to wait until disruption is over, due to handling costs, long detours, long lead time	Disruption duration needs to be known and honestly communicated to avoid unnecessary proactive action
[19]	closure/ capacity reduction rail, inland waterway	Mode and route shift generally decrease overall travel time in the network under disruptions Transport units change routes or mode in roughly 17% of all cases 64% of all transport units change mode, when inland waterways disrupted Switches to inland waterway are rare because of longer transport times	
[7]	Different failure scenarios Highway and rail	Response and recovery activities increase resilience Intermodal networks are more vulnerable than single-mode networks because of terminals but have more opportunities for recovery actions; Complete intermodal networks are very resilient because of high-redundancy Hub networks are very resilient when considering disaster response activities	
[28]	Road and rail, transport of cereals	Mode shift reduces delays of shipments under disruptions; Waiting for reopening of links is sometimes cheaper/faster than mode shift (especially inland waterway) Diverting from rail or inland waterway to road can increase costs between 500% and 1400% depending on previous mode and distance to destination Road disruptions do not cause any mode shift, trucks are just rerouted	Availability of infrastructure for changing mode (intermodal terminals), especially crucial in case study for inland waterways
[34]	Deep sea port closure with road/ rail access	Allowance of short sea shipping at the US coastline would have been a valuable alternative to road or rail-way transport Legal restrictions limit possibilities of mode shift	Regulations need to allow quick mode shift under disruptions
[22]	Capacity reduction / closure of alpine pass	Very large delays because of missing alternatives Multiple shipments switch from rail to road; rail network is less utilized Disruption preparedness can be improved by reserving transportation capacities for rerouting or quickly shifting to an alternative mode of transport	Operations at intermodal terminals need to be ensured (additional staff, backup equipment etc.)
[26]	Closure of a major port	Mode shift is economically more favorable than waiting for the port to reopen because of less supply chain disruption costs	Suppliers/shippers must be penalized for delivering late, as mode shift is more expensive than waiting
[23]	Capacity reductions / closures in intermodal network	Node and terminal disruptions more severe than link disruptions Under link and node (junction) disruptions, shipping is done with intermodal road and rail because of lower rail costs and redundant network structures Under terminal disruptions goods are shipped directly by road because highway network is redundant and cost-effective	
[31]	Multiple days strike of truck drivers	Road transport has a near monopoly for transporting finished products to retail stores, in general distribution logistics are predominantly conducted by road Freight terminals for rail mostly require collection or delivery by road missing rail links to factories, warehouses and shops limit mode shift Providing emergency infrastructure for railway access would take weeks	
[20]	Theoretical failure of a freight route	Second best routes are around 3-5% more expensive than shortest paths Reservation approach for supply chain management can increase flexibility Including different modes produced more options for alternative routes Reduced costs compared with road-only unimodal network resilience of supply chains improves by multi-mode transport capability	Availability of redundant mode access, transportation services, intermodal terminals; efficient redundant paths
[14]	Intermodal, disrupted link	Rail services often affected by disruptions; Rerouting and waiting preferred to mode shifting due to few transshipment nodes, and emergency service costs	Simulation-optimization Decision support system

From a network-theoretical point of view, optimized networks with few links are less resilient than highly connected networks. Multi-modal freight transportation networks based on intermodal terminals, hub-and-spoke operations, and few redundancies are mostly centrally connected networks, and therefore relatively unresilient.

However, when disaster response activities, like repairing of intermodal terminals or links, are considered, the resilience of those systems increases, because few interventions can restore large shares of the network [7], [30]. Road transportation is nearly always required anyway for the first/last mile transport to/from factories, distribution centers and especially shops, lacking access by other modes [31]. Therefore, a system-wide road network disruption (fuel shortages; earthquakes; or truck driver strikes, as described in [31]) is a threat to the entire freight transport system.

Mode shift identifies other bottlenecks: If the disruption or its management requests larger volume of freight to undergo mode shift, the intermodal terminals and related facilities will become bottlenecks of the system. In [18], discussing a rail link closure in U.K., intermodal terminals experienced less handling time per train and resulted in issues handling trains arriving out of schedule. In [22], the authors argue that additional staff or backup equipment needs to be ensured to keep operating the intermodal facilities under the special condition. Furthermore, certain links might not be able to handle much additional traffic due to rerouting and mode shifting from a disrupted link.

Vehicle volume plays a role in substitutability of modes: Different transport means have different volumes and pose challenges on mode shift responses. For instance, a typical barge in the coal supply chain network has a capacity of 1085t while a truck has only 25t [24]. A full mode shift from barge to truck would require offloading a large number of trucks; compared to a single barge. Thus, for some commodities and combination of vehicles, the road transportation cannot substitute inland waterway shipping. This issue is also present, while less strong, when switching for example from barge to train or from train to truck.

Embracing operational adjustments already from a planning stage: online control and synchromodality. Intermodal services organized with a synchromodal concept are reported by [32] to handle exceptional situations better than statically booked intermodal services. The same conclusion is reached in a dedicated study [13] on the topic of disruption response of synchromodally organized transportation services. In [14] the dynamic aspects of short disruptions against large disruptions is stressed as relevant, as the former can be included in offline planning, while the latter require dynamic interventions, which still need to tradeoff the costs of waiting for the costs of shifting mode. The costs and benefits of both actions depend on a dynamically unfolding situation. In any case the previous point applies, that actively taking action can be more costly than just waiting until the disruption is fixed.

Organizational issues limit theoretical potential: Transport operators and infrastructure managers (specifically, rail freight operators and railway infrastructure managers) are not prepared for coping with sudden disruptions [1], [18]. Business contingency plans are not in place and a-priori determined response or recovery measures are not defined [1]. Especially in the rail sector, risk reduction and management of natural disasters and of disruptions are organizationally complex: they need to involve many different stakeholders often from different countries and jurisdictions [33]. Disruption management can be improved if involved entities have updated contingency plans on strategic and operational level, to react quickly [18]. The organizational aspects are identified as important but often neglected in detail from academic studies. Post disaster transport operation are identified not just a technical question but also include institutional, managerial, readiness and legal aspects [34]. Overall, it can be expected that the efficiency that academic models evaluate for mode shift will be much smaller, when organizational aspects have to be taken into consideration.

V. EXPERT SURVEY

We perform a series of expert and industry interviews (besides others), based on the similar approach previously successfully applied by [18] in his study on the closure of a main rail link in Britain or by [1] in their study on rail freight under severe winter conditions. Freight transport differs from private transport as it has legally identified stakeholders, namely: (1) customers ordering freight transport services, (2) transport operators conducting the ordered services, (3) infrastructure managers, responsible for network operation, and (4) authorities and infrastructure owners, planning/building the infrastructure. In freight transportation and disruption response multiple actors are therefore to be coordinated. Their readiness and cooperation with each other strongly influence the success of contingency strategies. While this categorization is helpful, the experts we interviewed cannot be allocated uniquely to a category. Therefore, four more practical groups are identified: General experts, transport operators, industry, and government. The general experts include mostly scientists and consultants attached to the field of logistics or freight transportation. The government includes representatives from offices and agencies which work on transportation but are not infrastructure managers or providers.

The survey has been conducted over 18 experts, determined by an initial list of international experts and further by snowballing their suggestions. The experts are as follows: 4 transport operators; 2 experts from logistic department of industries; 2 experts from government; 11 experts with other roles or from academia, with many years of logistics experience (6 university professors in logistics or transportation; 1 senior researcher in logistics at university; 1 senior consultant and partner at a logistic consulting company; 2 senior managers for large rail and air logistic companies). The interview took places via email, phone or video conference tools. The experts were asked in a semi-structured way, to comment on the following aspects:

1) Can mode shift in response to a disruption in a multimodal freight transport network reduce its negative impacts?

TABLE 2. Aspects most mentioned by the experts.

Relevant aspect	Type	#
Duration of disruption	Time/space	8
Preparation and readiness	Involved actors	5
Rerouting options	mode	4
Size, shape, containerized	commodity	3
Hazardous material	commodity	3
Availability of information on disruption, alternatives, updated chains	information	3

TABLE 3. Constraints most mentioned by the experts.

Systemic Constraint	Type	#
Strict rail Regulation	Org	7
Information Shortage	Org	6
Missing experience with other modes	Org	4
Uncertainty on responsibility for bearing the disruption costs	Org	4
High cost of spare capacity to allow mode shift only exceptionally	Econ	3
Availability of terminals	Tech	2

Inherent Constraint	Type	#
Capacity constraints on other modes	Tech	7
Specific goods bound to a mode, like hazmat	Tech	4
Difference in transport capacity	Tech	4
Ability to handle increased complexity of transport chains including a mode shift	Org	2
If mode shift is required, market will react with higher prices	Econ	2

2) What are requirements on infrastructure and actors to adequately perform mode shift response activities in a multimodal freight transport network?

The answers are categorized according to the aspects identified; the constraints which limit mode shift; and the requirements for an effective mode shift.

A. ASPECTS

In total the 18 experts expressed 41 aspects; those recurring more often (last column identifies the amount of mentions) are reported in Table 2. Other aspects mentioned: scale, scope type and intensity of the disruption; distance of the shipments, time sensitivity, value, sensitivity to damages; ability to adapt the supply chain by for instance shutting down production; objectives of the involved actors. The most important aspects are analyzed in what follows.

The most prominent factor is duration of disruption. Mode shift is generally not considered efficient for short disruptions lasting only few hours, except if the readiness of involved actors is high, enabling quick and flexible mode shift.

This is especially the case if short notice mode decisions are the normal situation in day-to-day business, like in synchromodal paradigms. Most interview partners estimate from a mere duration perspective, that mode shift begins to be a sufficient tool, if disruptions last between one and three days.

Especially the industry and transport experts identified how preparation for quickly switching to rail is necessary in any case, and a higher degree of readiness is generally beneficial for the efficiency. The typical priority of actions sees rerouting on the own mode as the first option; mode shift is only a backup measure. The industry and transport experts are most aware how the specific type of good is a determining factor, as some types are not well suited for efficient handling in intermodal terminals

B. CONSTRAINTS

A total of 56 constraints have been identified; those recurring more often are reported in Table 3, separated in systemic constraint; and inherent constraints. Types considered are Organizational (Org), Technical (Tech), Economical (Econ). Other systemic constraints mentioned: handling possibilities; human factors in decision process; complexity of reverse logistics for empty wagons/containers; uncertainty about terminal capacity; IT systems not interoperable; information not digitally available; no decision support tools; high cost of mode shift. Other inherent constraints mentioned: last mile only possible by road; high coordination effort; lack of trust for sharing information. The most important constraints are analyzed in what follows.

Systemic constraints are caused by the current (legal, technical etc.) system and could be overcome with adaptions of the system or the behavior of actors in it. Inherent constraints represent constraints that are not caused only by external influences but by mode shift as a process itself. Removing those constraints will require major (practically unwished, or impossible) changes in for example the economic system.

While technical constraints are more agreed on by the interview partners, organizational and economical constraints vary focusing on different points. The main organizational issues are information shortages, and missing experience with other modes which is required to organize ad hoc mode shift. This is especially the case for rail transport, which poses high entry barriers on new customers. Larger, multimodal transport operators are better able to facilitate mode shift, than smaller operators because they have more experience and potentially also better information sources and cooperation with other operators. The need to organize the more complex transport chain might be especially difficult for smaller companies with less experienced staff.

A constraint limiting mode shift mentioned mostly by industry and transport experts is the uncertainty about responsibility for disruptions. It is legally difficult to

TABLE 4. Requirements most mentioned by the experts.

Relevant requirement	Type	#
Legally flexible contracts to allow mode shift	Org/ Info	3
Real time information exchange	Org / Info	2
Issuing operation permission, dependent on availability of a contingency plan	Org/ Plan	2
General support for multimodal transport	Policy	2
Amount of suppliers of multimodal shipment with open mode	Org	2
Standardization (e.g. containers)	Tech	2
More, further distributed terminals	Tech	2

determine responsibility for transport disruptions and therefore indemnity claims are often undisbursed. If for example a disruption is caused by force majeure, the customer is most likely fully bearing the financial risk. All groups of experts agree how freight transportation contracts are often long lasting and must be paid, also under disrupted conditions. Hence, customers might be afraid of paying twice if they shift mode and indemnity claims are void.

Choosing the most efficient transport solution under usual conditions pushes other alternatives out of the market and leaves less options for shifting under disruptions. Capacity constraints are most relevant for link infrastructure and less for node infrastructure. Terminals are said to have often spare capacity available and moreover capacity can easily be increased with additional personnel. Node disruptions are irrelevant for the interviewed experts, which might be caused by lack of experience due to few recent events or because enough terminals with sufficient capacity are available.

C. REQUIREMENTS

A total of 23 requirements have been identified; those recurring more often are reported in Table 4, separated by type into Organizational (Org), and further related to Information (Org/Info) or Planning (Org/Plan); Policy; or Technical (tech). Other requirements mentioned: more sensors for early disruption detection; more infrastructure redundancy; optimized decision support tools and risk assessment procedures; clear institutional and legal basis for data exchange; faster post-disruption response; plans for disruption available on beforehand; foster more balanced mode shift already in normal operations. The most important constraints are analyzed in what follows. Having a more balanced use of modes on freight relations distributes flows to different modes.

Such systems, and also holistically integrated transport systems are best to tackle disruptions, because there are less single points of failure and capacity is distributed on multiple infrastructures. Future technologies like truck platooning can introduce further alternatives, which are able to support resilience in the transportation system.

In the last years, vulnerability awareness and thinking about resilience got hold in the industry and especially the transport sector. Despite that, most experts doubt that resilience and vulnerability are widely acknowledged as important topics in transportation.

Service driven companies with a vertically integrated structure with own rail services and access to the rail network have the advantages on autonomy and information. Such an integrated company does not require extensive coordination or cooperation with unacquainted partners or competitors, when readjusting the transport operations and possibly performing mode shift, under disrupted conditions.

Good practices include cooperation with large transport operators, which can offer various modes for international transports and also use different infrastructures (e.g., North Sea and Mediterranean ports) to increase the resilience of their supply chain. All partners in the supply chain have contingency plans and make them available to the partners; and have special arrangements to be able to quickly request additional capacities if necessary.

Some requirements depend on the commodity itself; or its shipment in bulk or standardized units such as containers. For instance, heavy equipment, hazmat, or special cargo prone to damage caused by additional handling might not be easily shifted; in general, additional handling is avoided for what is possible. Another limiting factor for mode shift arises when input and output material for/from industrial processes are not transported in standardized units. For those cases, waiting and rerouting in case of disruption are preferred.

Rail operators are bound to many contractual and legal aspects. Rail operators consider rerouting of trains as their first response to disruptions; and mode shift only as a second response. If mode shift is necessary, the process is not organized by the company itself, but is in responsibility of the customer. The experts agree that switching from another mode to rail is hindered by the strict regulation of the rail sector, which poses high entry barriers for unexperienced companies

If trains are stuck on the tracks, some rail operator might support their customers with services to transfer goods to trucks. For some other operators, it is reported that customers are better able to organize a new transport chain by shifting mode, than the operators themselves; as those latter miss partners and experience. Cooperation under disruptions is common and includes mostly pooling of resources and selling or buying of traction units, respectively.

In the European rail infrastructure, the general concept of network neutrality applies. Hence, no transport operator is privileged, and disruption measures can be coordinated between different operators. The situation is different in for example the USA, where the rail networks are privately owned and operated by the railway companies themselves.

The political landscape of subsidies/taxes to specific modes (for instance, discouraging road transport) is also important. Therefore, if a mode shift is implemented, the goal is to keep as much freight as possible on sustainable modes (rail and inland waterway), because shifting to road is often not reversed after the disruption is solved.

Also a political aspect pertains the responsibility on who takes action on critical or noncritical cases. For instance, in Switzerland the Federal Office of National Economic Supply (FONES) is allowed to take measures for the logistics sector (easing of the night or Sunday ban for heavy truck transport, temporary more flexible working hours for truck and train drivers, temporary use of technical maximum weight of trucks above legally allowed maximum, prioritization of train paths and terminal slots for scarce goods, extension of customs opening hours at the borders). Those measures have large impact on the possibility and effectiveness of a single mode, and of mode shift in general. However, these measures are only used if a critical supply situation is reached and the transport system cannot deliver necessary products for the national economy or society anymore. Until that moment, the market system is fully responsible for responding to disruptions [35].

VI. DISCUSSION AND CONCLUSION

Much optimization and control approaches have been defined for freight transport, also including the relatively rare, but economically relevant case of major disruptions. Those optimization approaches though are most often remaining in the academic world; and multiple barriers are evident for a widespread usage of them. In this work, we studied this complementary problem, of where and why which barriers exist, limiting the application of optimization tools, confined within the narrow question of mode shift during disruptions. For the most relevant barriers we also discuss now the possible solutions that would enable full potential. The general focus of current academic research is more on technical aspects, while many aspects have an organizational nature. An overview of parameters influencing the likelihood of performing mode shift is presented in Figure 1.

Both technical components and organizational components have a similar influence on mode shift likelihood, during disruptions. Those can be both considered as barriers, and solutions, as far as they are influenceable. Many influenceable parameters are of organizational nature and pertain information shortages (which can be solved by better information collection management, and sharing); capability of customer and transport operator to conduct mode shift (which can be solved by infrastructure, personnel and know how); suitable contractual and regulation environment (which requires legal frameworks, and agreements between the stakeholders). Industry standards in transportation help in simplify quick mode shift, ranging from hardware (containerization or wagons) to software (IT-Systems for data exchange). In contrast, non-influenceable factors are given by the disruption process and the transport chain themselves or by inherent constraints. They largely contain technical components and parameters. Solutions in this case would need to be identified not in the disruption management, but in other parts of the planning, like contingency planning, and inclusion of robustness and resilience when designing the supply chain.

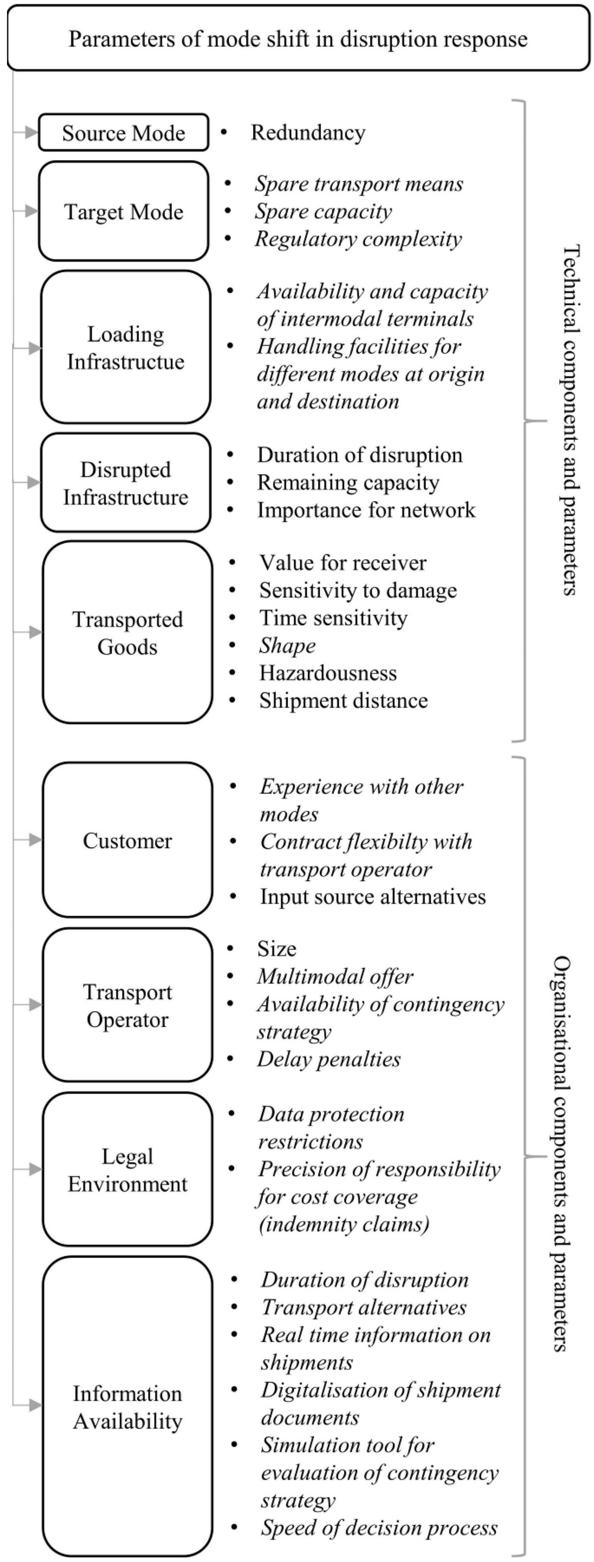

FIGURE 1. Influencing components and parameters of mode shift in disruption response. Italic parameters are identified as directly influenceable by for example policy changes.

Those aspects might receive stronger importance, following known trends in transportation and logistics (see for example [36], [37]). Integration and collaborative decision making is required whenever the information and actions must be agreed on multiple stakeholders. As collaborative decision making gets more prominence, the organizational issues identified in the present paper will need to be solved, to enable a performant implementation in practice. The trend to include non-structured shippers, like in crowd-shipping, will also require the need to operate with stakeholders which are outside of the standard logistics categories. Structures mixing competition and cooperation, as often proposed for city logistics, would require careful solution (by third parties, orchestrators, authorities) of many organizational and decisional issues here identified.

Current freight transportation models studying disruption response do not accurately account for mode shift; they especially miss, or greatly simplify organizational and technical factors. A complete digitalization of the processes and goods exchanged, and precise reporting of constraints and rules, would allow modeling and simulation of many infrastructural, decisional and organizational aspects here identified, thereby extending the models in the state of the art.

The trend to have smaller shipments, with higher volatility, and stronger time constraints will result in different solutions to the tradeoff between waiting or changing mode, and probably support transition to inherently mode-generic solutions such as synchromodality. Stronger pressure for sustainable supply chains, and possibly electric vehicles, might result in tighter constraints for link speed and capacity, and provide further points that can get disrupted.

Mode shift alone is not able to create resilience, and is a solution to disruptions only if accompanied by redundancy building (i.e., sufficient capacity on alternative links). Large scale mode shift under disruptions exploits available spare capacities; terminals need to have sufficient amount and capacity, but also have available optimized contingency strategies, for a quick reaction. Intelligent decision support during planning and during operations can help take the right decision and require platforms for data sharing and collaborative decision making.

In freight transport, the general focus of current academic research is more on technical aspects; while many aspects have an organizational nature. Research has also identified how modelling intermodal freight networks with spatially explicit characteristics, based on detailed geographic information system (and not a simplified graph theory model) yields more realistic results [13].

Mode shift can be a sufficient tool under disruptions, and further supporting measures can further increase its efficiency. Those measures span from regulatory framework and organizational issues (especially for rail) to infrastructure availability. Mode shift response is always a question of price and willingness to pay. The constraints identified most often are not hard barriers, but extra costs for mode shifting, for necessary technical and organizational effort. However, mode shift is not inherently desirable. Customers and transport operators design/choose the most efficient transport chain for their specific goal; a mode shift always increases costs and complexity from this optimum. Mode shift requires equipment and time, thus reducing efficiency. Strategic interest from authorities might compensate those efficiency losses, fostering inclusion of flexibility at a planning stage, and/or support of synchromodal approaches. The ability and willingness to perform a mode shift cannot compensate a limited redundancy in the transport system. Costs for redundant resources must be borne by someone (e.g., customers of freight services, taxpayers etc.). The tradeoff between financing these redundancies for a better management of future uncertain disruptions and tolerating cancelations and delays must be solved by a fair quantitative assessment of consequences.

Future research on this aspect should focus on how to turn possible organizational barriers into opportunities, and finally allow the full potential of the optimization models. This could be based on detailed analysis of infrastructural, decisional and organizational aspects from cases studies, aiming at identifying which decision could have been taken differently, if optimization models are available, and organization would implement their input. Many barriers identify solution pertaining strongly to policy aspect, in terms of regulations, financing, taxes, and can only be discussed and changed in the appropriate level. Finally, many recommendations from the current study pertain data availability and sharing, as well as standardization of processes. Solutions on this aspect have been well identified in the literature as collaborative platforms where cooperative or competitive stakeholders can interact [14], [36]. A review of best practices in those directions, in the wake of persistent, planned or unplanned disruptions, would increase the resilience of the entire freight transport network. Finally, a database of disruptions, described in quantitative terms, and organizational aspects, and dynamics, is useful towards policy makers and practitioners, to achieve smoother and effective processes, and perform replays of past situations.

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