# BAD LOCATIONS, BAD LOGISTICS? HOW NORWEGIAN FREIGHT CARRIERS HANDLE TRANSPORTATION DISRUPTIONS

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## ABSTRACT

Transportation networks, and in particular road networks are an integral part of supply chains, and in regions with sparse networks this road network becomes very important. How are the supply chains of companies located in sparse transportation networks affected by transportation disruptions? What are typical disruptions in certain locations or for certain types of business, and how do businesses and carriers counter supply chain disruptions? This chapter is based on a 2009 study from Norway, aimed at investigating how businesses and freight carriers located in sparse transportation networks are affected by and relate to supply chain disruptions. The study indicates that transportation-dependent businesses seek a vertical integration of a freight carrier into their supply chain, while freight carriers establish flexible solutions to meet the contingent needs of different businesses. The study also develops a new framework for the categorization of supply chains, and introduces the notion of the constrained supply chain.

*Keywords: supply chain risk, sparse transportation networks, road transportation, transportation disruption, freight carriers, risk management*

## BACKGROUND

Transportation networks are the main backbone of modern society and play an important role in supply chains. Consequently then, the reliability of the transportation network or the reliability of supply chains is thus a decisive factor not only in terms of market outreach and competition, but also in terms of continuity, to ensure a 24/7 operation of the community we live in. Any threat to the reliability of the transportation network constitutes a vulnerable spot, a weakness in the supply chain.

The vulnerability of the transportation network has been the subject of academic research for some time (Dalziell and Nicholson, 2001; LLeras-Echeverri and Sanchez-Silva, 2001; Berdica, 2002; Di Gangi and Luongo, 2005; Husdal, 2005; Jenelius et al., 2006; Taylor et al.,

2006), and the importance of transportation networks in supply chains and freight distribution has also gathered considerable interest (Svensson, 2002; McKinnon, 2005; Sanchez-Rodrigues et al., 2008; Heaslip et al., 2009; Husdal, 2009; Ta and Pitera, 2009, Sanchez-Rodrigues et al., 2010), thus indicating a strong link between transportation research and supply chain research.

The vulnerability of the transportation network as part of the supply chain is of particular interest in countries or regions with sparsely populated areas, and hence, a sparse transportation network. Typical traits of such regions are few transportation mode options and/or few transportation link options for each transportation mode, for example maybe only one railway line and two roads, no port, no airport. It should not come as a surprise then that the nature of sparse transportation networks, and thus sparse supply chains, makes them vulnerable to many different kinds of internal and external risks. With only a few transportation modes and links available between population centers, these population centers become extremely vulnerable to any disruption in the transportation system or supply chain, since in a possible worst-case scenario no suitable alternative exists for deliveries to or from these communities.

From the community is as important as to the community, since the supply chain goes both ways, meaning that no goods or supplies can come in and no manufactured goods or supplies to companies in other locations can leave. Few will question that the sender, the recipient, the freight hauler, or society at large, experience additional costs when goods or people cannot reach their destinations in time or in space. A non-functioning, or at best, badly-functioning link will impose costs on the user in terms of loss of time, additional operation costs or other costs as a result of delays and diversions. Transporters of perishable goods will also experience a loss of value.

A study commissioned in 2008 by the Norwegian Public Roads Administration has investigated how companies located in sparse transportation networks are affected by and relate to supply chain disruptions (Husdal & Bråthen, 2010). The companies were selected across industry sectors, presumed to be heavily reliant on road transportation, and presumed to be geographically challenged, i.e. unfavorably located in a supply chain setting. This chapter reports on the framework that was developed for the study and on the findings from interviews with selected companies.

# THE ROLE OF TRANSPORTATION IN SUPPLY CHAINS

## Transportation effects in supply chains

All products are the result of a chain of events, whereby raw materials or supplies are processed by a manufacturer and distributed to a retailer or directly to an end customer. These processes ore often linked in a very complex manner and supply chains are therefore better seen as supply networks, and not chains. The transportation network plays an important role in securing the flows of materials within this supply network, and an unreliable transportation network comes at an extra cost: It may cause the supply chain players (n-tier suppliers, company and n-tier customers) to hold an unnecessarily large buffer stock or safety stock. Likewise, an unreliable transportation system causing uncertainty as to

scheduled or planned delivery times may, cause the manufacturer to have to shut down temporarily while waiting for supplies, or at best, reduce the production volume, resulting in lost sales, and in worst case, closure. Non-delivery of planned supplies may cause the manufacturer to seek alternate solutions that often come at an increased cost of first sourcing substitute supplies and then leveraging enough manpower to honor contractual agreements (i.e. lead time) towards a customer. Finally, there is the transportation cost itself, since the aforementioned will result in extended operation of trucks and equipment, overtime wages for drivers and increased maintenance. It should clear then that a transportation network that does not match the needs of the supply chain, potentially can impose higher costs on the supply chain that would otherwise be the case.

The importance of road networks in Norwegian supply chains

Together with sea transport, road transportation is Norway's major mode of transporting goods. According to the 2007 records by Statistics Norway, measured in ton kilometers, transportation by road comprised 48% of the total, by sea 46% and by rail 6%, compared to 79%, 7% and 15% respectively in the EU-15 countries, as reported by the 2009 statistics from the European Road Federation. While this may appear to give roads a lesser weight in goods transportation in Norway than in Europe, it should be borne in mind that Norway, compared to most of Europe has a very sparse road network, as is well illustrated in figure 1, showing same-scale maps of the road network in Norway and Europe, both taken from an online route planner. Lack of details and missing minor road links aside, it is clear that Central Europe enjoys a much denser road network than the Scandinavian countries, and Norway in particular, and hence has many more rerouting options in case of disruptions. For instance, the road density in Norway is 0.3 km/km2, Denmark has 1.7 km/km2 and Belgium 4.9 km/km2. Thus, it would appear that supply chain disruptions on roads may have potentially more severe implications in Scandinavia than in the rest of Europe.


Figure 1 - The sparse road network in Norway and Sweden compared to the dense road network in Central Europe. (Source: viamichelin.com)

The East-West running road links (and many of the North-South links) in Norway have to traverse mountain passes that are frequently closed in winter, while the roads along the Western and Northern coast are intermittently "broken" by ferry services. The main corridor between Bergen and Trondheim, Norway's 2nd and 3rd largest cities, has five ferry links over a distance of 660 kilometers (marked by the dots in figure 1, left). All in all, there are some

127 ferry links on public roads in Norway, with annual average daily traffic ranging from more than 4000 vehicles to less than 100. Ferries play a major role in travel time reliability, or rather "travel time uncertainty" in road transportation in Norway, since many ferry links do not operate on a 24/7 basis, but reduce or cease operations during nighttime or weekends. In many cases there is also no alternative to the ferry link. This makes transportation-related decision-making in a sparse network different from a non-sparse network. Laird (2005) contends that the option value that individuals hold for the ability to use transportation resources in such external circumstances are far above and beyond the direct value of consumption, because in sparse networks, the consequences of uncertainty surrounding the availability of the transportation network can be severe and potentially irreversible: Missing the last ferry for the day or needing emergency care not provided locally and after ferry hours are just some of the examples that come to mind. The transportation of goods is affected similarly: Missing the ferry when transporting perishable goods that need to arrive the next morning, or missing the ferry in a just-in-time supply chain with little or no slack for delays are not unknown incidents in Norwegian supply chains.

One way or the other, all production and manufacturing depends on roads for bringing their finished goods to the market or for supplying the production facilities with raw materials. Even materials or goods that are transported by sea or rail are sooner or later transferred to a truck, even if only for a short distance. All business sectors and industries are thus dependent on a well-functioning road network. Given the large percentage of freight transport by road, supply chain disruptions due to transportation disruptions ought to be a major concern for any businesses or communities particularly if they are subject to sparse transportation networks.

Some of the reasons why road transport is the preferred means of freight transportation are short processing times from when the order is given until the actual transportation commences, flexible departure and arrival times and locations, flexible transportation volumes and the possibility of fragmenting or consolidating many orders to and from many destinations with very few or perhaps only one vehicle. This is not possible with freight transport by sea or rail, which more often than not must follow scheduled departure times that do not always match the requirements of the freight owner. Even were intermodal solutions exist, freight owners tend to be wary of using them, mainly for fear of unreliable delivery times, possible breakage during multiple handling operations, and lesser control with the transport itself. Once the good is loaded onto a truck, the freight owners knows where it is and how to get to it, should the need arise. That is not always possible with rail or sea, although RFID may be able to solve some of these issues.

## The transportation network as critical infrastructure

Research into Critical Infrastructure has attracted considerable interest during the last decade, particularly since 9/11, but already in the mid and late 1990s Critical Infrastructure established itself as research field. In Norway this is exemplified by the research project 'Protection of Society' (POS) or 'Beskyttelse av Samfunnet' (BAS in Norwegian), undertaken by the Norwegian Defense Research Institute, FFI, in cooperation with the Norwegian Directorate for Civil Defence and Emergency Planning, DSB, and which published their first report in 1997 (hæsken et al., 1997). The objective of the first BAS project report was to

describe how modern society will react to and can protect itself when facing modern warfare. In doing so, the report identified key components and functions that are essential to a modern society, and interdependencies between them, see figure 2.

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Management /Government | | XX | XX | | | X | | | X | | | | X | XX |
| 2 | Power supply | X | | XX | X | | X | | | | X | | | X | |
| 3 | Telecommunications | X | XX | | | X | X | | | | X | | | X | |
| 4 | Oil and Petrol | X | XX | X | | XX | | | | X | X | | | X | |
| 5 | Transport | X | X | X | XX | | XX | | | XX | X | | | X | X |
| 6 | Work force and Labour | XX | XX | XX | | X | | X | X | | | X | XX | | |
| 7 | Water supply | X | XX | | | | | | | | X | | | | |
| 8 | Banking and Finance | XX | XX | XX | | | | | | | | | | X | |
| 9 | Construction/Engineering | X | X | X | XX | XX | XX | | X | | X | | | | |
| 10 | Industry and Business | X | XX | XX | XX | XX | XX | X | XX | | | | | X | |
| 11 | Health services | X | XX | XX | | XX | XX | XX | | | | | XX | X | X |
| 12 | Food | X | XX | XX | | XX | XX | XX | XX | | XX | | | X | |
| 13 | Fire and Rescue services | XX | X | XX | | XX | X | XX | | X | | | | | XX |
| 14 | Police and Public order | XX | X | XX | | X | X | | | | | | | | |

Figure 2 - Interdependencies among critical infrastructures or sectors

In figure 2, a cross along the column marks that this sector is necessary for the sector in the corresponding row. A cross along the row marks that this sector is dependent on the sector in the corresponding column. The transportation sector stands out as one of the more important sectors.

In two later reports (Hagen et al, 2003; Hoff, 2003), the BAS project looked closer at the importance of maintaining a well-functioning transportation infrastructure, and what impact that transportation disruptions might have on the other important sectors in society. Figure 3 summarizes the findings, showing the degree of impact depending on the length of disruption.

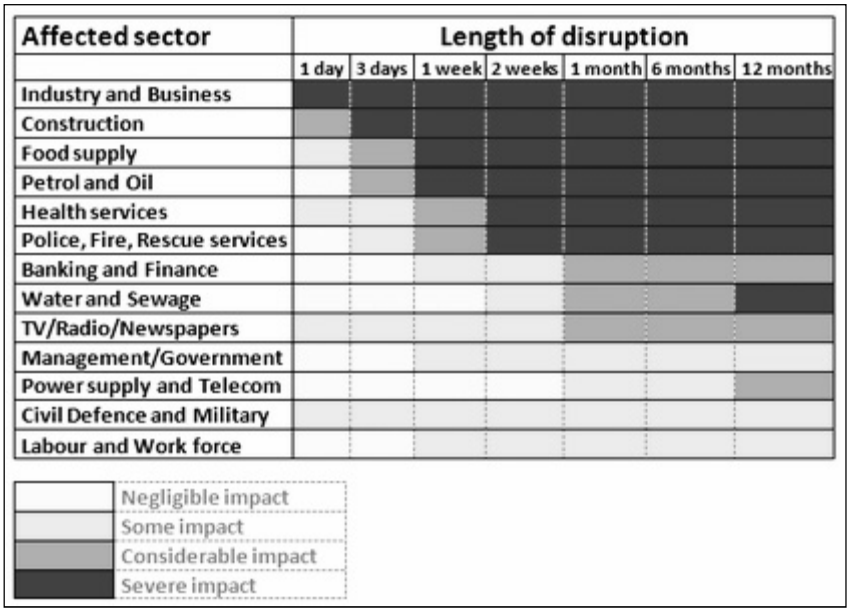


Figure 3 - Consequences of transportation disruptions on different societal sectors

Figure 3 shows that transportation disruptions already after one day have a severe impact on sectors dependent on the distribution of goods and supplies, while banking and finance appear to be relatively unaffected by transportation disruptions. Similar findings can also be seen in McKinnon (2005), who investigated the effect of transportation disruptions for the UK. The reason for the immediate impact of transportation disruptions is that the manufacturing industry and also wholesale and retailing due to an increased reliance on just-in-time deliveries are a major consumer of transportation services. A small number of production facilities are perhaps supplying a large geographic share of the market, and a transportation disruption will mean that no raw materials can be delivered to the factories and no finished goods can be transported to their point of sale. Buffer inventories or safety stock are the only possible mitigative measures here.

## A framework for supply chains in sparse transportation networks

Obviously, if the transportation network forms parts of the supply chain, the overlying supply chain is affected by the underlying transportation network. A transportation network consist of different modes (road, rail, sea, air) and links for each mode. In a sparse transportation network neither modes nor links are a matter of choice, and the supply chain is effectively "locked" to the existing options, i.e. modes or links. When the number of transportation options decreases, and a disruption occurs, then the vulnerability increases, since there is lesser flexibility, say, in re-routing deliveries via different modes or links.
A supply chain that is subject to a sparse transportation network cannot be set up freely, but is limited by constraints, mainly transportation mode choice (air, sea, rail, road) and transportation link choice within each mode. This can be termed a "constrained" supply chain.
Taking both modes and links into consideration, transportation networks or supply chains can thus be divided into four principal types of networks or supply chains: Free, Directed, Limited and Constrained. Figure 4 illustrates this division. In a free supply chain there are little or no constraints as to transportation modes and there is a dense transportation network with many possible links. In a directed supply chain there are many possible links, but few modes, thus directing the supply chain towards a certain mode or set of modes. In a limited supply chain there are many mode choices but few links, which creates an overall limited setup. In a constrained supply chain there are few choices as to mode and/or links and in worst case the supply chain is locked to one mode and very few, or maybe, only one link.

| | | MODES | |
|---|---|---|---|
| | | Few | Many |
| LINKS | Dense | Directed Supply Chain | Free Supply Chain |
| | Sparse | Constrained Supply Chain | Limited Supply Chain |

Figure 4 - Four categories of networks or supply chains, based on the number of modes (rail, sea, air, road) and number of links within the modes that are available.

Admittedly, this is a very crude classification scheme, since a "free" supply chain with all modes available, but with capacity constraints on all or some of the links and/or modes is no longer a true "free" supply chain. Capacity constraints could become a factor that would turn a seemingly free supply chain into one of the other types of supply chains. The classification scheme does also not take into account differences in costs related to using the modes and/or links, and similar arguments as with capacity constraints will apply for this.

# TRANSPORTATION RISKS IN SUPPLY CHAINS

## Risks

Risk is an ambiguous concept, therefore there are many definitions of risk, depending on their specific application and on their situational context. One of the most common meanings is that of risk as a threat or danger. In addition, risk often implies the probability of a negative outcome. Harland, Brenchley & Walker (2003) define risk (R) as the product of the probability (P) of a loss (loss) and the significance or impact (I) of the loss, related to an event n (n):

$$Rn = P(loss)n \times I(loss)n$$

Supply chains and are exposed to a wide range of risks, and there is an ample body of research literature on supply chain risk, which we for the purpose of this paper will not discuss in any detail. Suffice it to say that the following is a list of typical transportation risks that can lead to disruptions in incoming and outgoing flows in supply chains:

- Accidents and engine/vehicle breakdowns
- Lack of spare parts or lack of facilities and resources for repair
- Lack of fuel
- Weather and road conditions
- Errors in loading, e.g. mixing hazardous and non-hazardous goods
- Theft
- Strikes and other work-related issues
- Disregard of rules and regulations (e.g. driver resting hours)
- Bankruptcy or other financial difficulties at other players in the supply chain
- Wrong or erroneous driving/loading permits
- Wrong or erroneous documents, e.g. customs declaration
- Wrong or erroneous information from and to other players in the supply chain

The list is potentially endless, and the above examples are not meant to be exhaustive. For the research presented later in this paper we decided to use the generic risk definition found in Kaplan (1981), which is also used in Cova and Conger (2004) for transportation risks and in Paulsson (2007) for supply chain risks. This definition splits the concept of risk into three different elements, together called a triplet. Each triplet identifies a risk scenario, involving a source, likelihood and an impact.

- What can happen and what is the cause?
- How likely is it that it will happen?
- If it does happen, what are the consequences?

A risk can be seen as incompletely described unless all three elements are in place. In risk management, addressing the impacts is an important issue, which is why the consequences need to be considered along with the likelihood and source of risk.

## Risk drivers

There are many risk factors that can affect the performance of a supply chain, and not all factors will carry the same weight. Moreover, there can be huge differences from industry to industry and between companies in the same industry, and a risk assessment will always be a company-specific assessment. For instance, for a company located on an island, the ferry link may be the greatest cause of transportation disruptions, while a company that imports materials from abroad may rank delays, e.g. due to customs clearance, at the port of export or import as the most important risk factors. The term transportation disruption refers here to disruptions either in form of a badly-functioning or non-functioning infrastructure or disruptions in form of a badly-functioning or non-functioning vehicle using the infrastructure.
Jüttner, Peck & Christopher (2003) use four basic constructs in their approach to supply chain risk management: 1) Sources of risk, which lead to 2) Adverse Consequences of risk, instigated by 3) Drivers of risk and possibly offset by 4) Mitigation strategies. Following the view of Asbjørnslett (2008), risk addressing strategies ought to be differentiated into mitigative strategies (reducing the exposure to risk sources and drivers) and contingent strategies (reducing the impact of consequences). Figure 5 illustrates this concept, where mitigative strategies address sources and drivers, while contingent strategies address impacts.

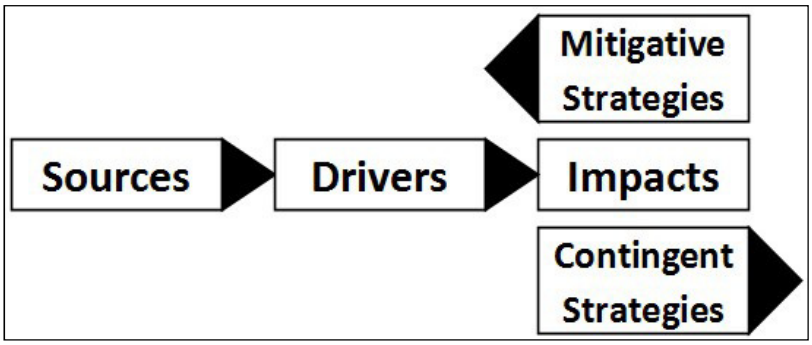


Figure 5 - Risk management strategies need to be mitigative and contingent. Adapted from Jüttner et al. (2003) and Asbjørnslett (2008)

Which strategy that works best will depend on the situational context and the resources available. In relation to freight transportation, on one hand, a slack in lead time can be viewed as a mitigative measure in order to counter delays, say, due to engine failure. On the other hand, a reserve or replacement vehicle (which can also be contracted through a

partner carrier or forwarder) for transferring the goods from the broken vehicle in order to secure delivery can be considered a contingent measure.

## Risk sharing

Transporting goods from one place to the other will always have a risk of the goods not arriving on time or in broken condition, and a transportation company (i.e. freight carrier) that accepts a transportation order from a freight forwarder or directly from a freight owner will want to clearly identify and contractually determine which party that is bearing which risk. Extra transportation costs will possibly occur in case of engine breakdowns, avoidable delays or unforeseeable detours, some of which may in hindsight have been foreseeable, the cost of which should ideally be fairly shared among the parties involved. If on-time delivery is imperative, the freight owner may demand the carrier to install systems for tracking and locating vehicles and or goods, and orders may be relayed directly from the freight owner to a certain vehicle of the carrier company, something that may affect the sequence of other orders the carrier has to undertake that day. The type of goods carried may demand increased vehicle maintenance or may require the carrier to invest in certain equipment for loading and handling. Such equipment typically has a high investment cost, but decreasing average costs, something that may lead the carrier to seek a long-term relationship with the forwarder to cover the costs that have been occurred in relation to this particular type of goods. In long-term contracts, there may be other uncertainties, e.g. fuel costs may unexpectedly rise or there may be changes in government health and safety regulations and driver resting hours, items that are typical candidates for a re-negotiation of the contract terms. The risk sharing principles prescribe that risk should be borne by the party closest to the risk source, and thus is the party most able to “control” (through mitigative or contingent actions) any consequences stemming from the risk. In practice, this means that the carrier should bear any risks associated with equipment, vehicles or infrastructure-related events, while the freight owner is best suited for handling risks associated with delivery times or risk related to suppliers and sub-suppliers of the goods transported.

## Addressing transportation risks in sparse supply chains

Combining the notions on supply chain risk sources and drivers in Jüttner et al. (2003) and the notions in Craighead et al. (2007) that supply chain characteristics play a major role in supply chain disruptions, we can say that one side a supply chain is exposed to certain risks, that may (or not) lead to certain supply chain disruptions. On the other side the supply chain has certain characteristics, which determine the supply chain vulnerability. The severity of supply chain disruptions is related to supply chain design characteristics (supply chain density, supply chain complexity and node criticality) and supply chain mitigation capabilities (recovery capability and warning capability). In brief: supply chain structure and supply chain organization. The impact of supply chains disruptions depend on a) the structure and b) the organization of the supply chain, where the structure makes up the physical side (a) of the supply chain and the organization makes up the human side (b) of the supply chain. These two parts are complementary in that both are needed for the successful handling of a supply

chain disruption, while at the same time, a deficiency in one part can be compensated by the strength of the other part, i.e. a badly structured supply chain can be strengthened by a well organized supply chain. Within this framework, a company can address supply chain disruptions in two ways: 1) Redesign the supply chain towards a better structure, in order to gain a better location, or 2) Redesign the supply chain towards a better organization, in order to gain better preparedness. This is shown in figure 6.

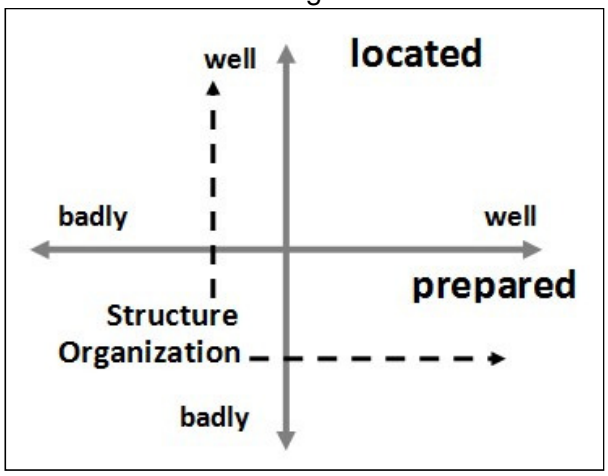


Figure 6 - The influence of structure and organization on a company's preparedness and locational favourability

The supply chain structure will be closely linked to the four types of supply chains mentioned earlier, and in the case of constrained supply chains, the structure is fixed. Consequently, the only point of attack for overcoming transportation disruptions is increased preparedness.

# TRANSPORTATION DISRUPTIONS IN SUPPLY CHAINS

## Framework for case study and interviews

The initial design of the aforementioned study commissioned in 2008 called for a structured interview of 15 transportation-dependent businesses, and an investigation of the consequences and costs of transportation disruptions to these businesses. The interviewees were contacted by phone or e-mail and the interviews were conducted by phone after the respondent had received a questionnaire by e-mail. Unfortunately, as interviews progressed, only three businesses decided to fully participate. These interviews revealed, however, that the manufacturers had forged close relationships with selected carriers that had established systems for handling disruptions or that had a proven track record for their services, and it thus became apparent that it was the carriers who literally carried the brunt of consequences that came with disruptions, which is why 14 selected carriers then became the focus of our investigation. The general framework for the interviews is seen in figure 7 below.
The first part of the questionnaire was meant to confirm whether or not the following parameters had an influence on the occurrence, the impact of and the preparedness for transportation disruptions: Size of fleet, type of fleet, strong ties to one or several freight owners (i.e. businesses dependent on their services), regular (schedule-based) or irregular (order-based) transport missions. The interviewees were asked to estimate on an annual basis the percentage of transports that were severely disrupted, i.e. disrupted or delayed

beyond normal expectations, i.e. the actual exposure to disruptions. Conversely they were also asked to give a value for their perceived exposure to disruption on 1-7 scale. In addition, we asked the carriers for examples of severe incidents, and which mitigative or contingent measures the carriers employed. Finally, the respondents were asked to name particular challenges they would like to highlight as their major sources of transportation disruptions.

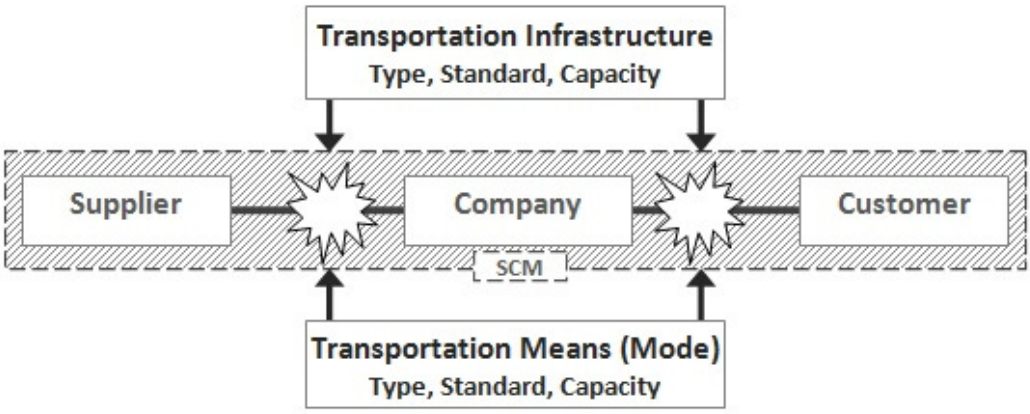


Figure 7 - Framework for investigating cause and effect of transportation disruptions in supply chain?

The following is a summary of the findings, based on interviews with the three transportation dependent businesses and the 14 freight carriers/forwarders. Given the very small data sample, the results are admittedly highly selective, but they do indicate that the performance of the freight carriers and the relationship between freight carrier/forwarder and freight owner are a major contributor to the overall supply chain performance.

## Data Sample

The 14 transportation businesses or freight carriers varied in fleet size, geographical base, length of haul and main type of goods transported by the carrier: tank trucks, dry bulk trucks, refrigerated trucks, container trucks, and “special” trucks (flatbeds and similar). While the sample size is admittedly small, it still managed to capture a selection of carriers across goods carried and fleet size operated, along with a sufficient average haul length that captured dominant geographical challenges such as ferry links, varying road standard and mountain passes.

## Size of fleet

The number of trucks in operation on any given day varied between 6 and 90, with an average of 29. From our sample, we could not see a connection between size of fleet, actual or perceived exposure to disruptions, and number or type of mtigative and contingent measures. A large fleet size, and hence greater flexibility if a disruption occurs is compensated for partnership agreements with other carriers by the smaller fleet owners.

## Type of fleet

All carriers had to a lesser or larger degree invested in special vehicles or equipment for loading and handling in order to satisfy certain customers, or as a result of contractual requirements issued by the freight owner, but very few investments had been made as a mitigative measure vis-à-vis disruptions.

## Cooperation and ties

We asked for the percentage of the annual revenue from the three most important customers, to see whether close links or ties to a certain customer made any difference in the actual or perceived exposure to disruptions or to the amount of mitigative efforts. While the percentage of annual revenue coming from one customer varied between 9% and 100%, with an average value of 52%, it was not possible to conclude from our limited sample that close links or ties had a direct effect on disruption frequency, neither perceived nor actual, nor did it have an effect on mitigative measures.

## Actual and perceived disruptions

The interviewees were asked to estimate the percentage of transports that were severely disrupted, i.e. disrupted or delayed beyond normal expectations. Delays in loading and unloading, missing a ferry, roadside accidents, scheduled pick-ups or deliveries that are cancelled and minor mishaps are daily occurrences in transportation, but they rarely cause severe consequences. This was confirmed by the carriers, who estimated that between 0.5% and 5% and on average 2.6% of transports were strongly affected by disruptions. It should be noted that the percentage number here is a qualitative estimate; it should also be noted that this number did vary geographically, indicating that seasonal and locational factors play a major role. As to perceived exposure to disruptions, the carriers were asked to answer on a 1-7 scale, (1 = no exposure, 2 = very low, 3 = low, 4 = little, 5 = some, 6 = high and 7 = very high exposure) On average, the perceived exposure turned out as 3.6, low or little exposure, varying from 1 to 6 individually, again indicating local and seasonal differences. The sample was inconclusive as to establishing a relationship between the exposure and the other variables.

## Incidents

To gain more insights into the nature of transportation disruptions, we asked the carriers to report the most recent severe disruption incident and its consequences. Below is a shortlist of some of the responses given:

- Late arrival of perishable goods (fresh fish) to marketplace. Carrier had to reimburse the loss of value from selling a low-quality (not fresh) product
- Truck driver stops in accordance with driver resting hours. Misses ferry, resulting in further delays en route.

- Road closure due to roadwork. Truck cannot reach manufacturing facility, which has to shut down temporarily.
- Roadside accidents. Foreign (i.e. European) drivers not accustomed to the Norwegian weather are often stuck on mountain passes in winter.
- Ferry link safety issues. The regular vessel is taken out of service and safety regulations prohibit the substitute ferry from carrying too many trucks with hazardous goods or prohibit the ferry from carrying such goods at all, resulting in a long detour and further delays,
- Ferry link capacity issues. If there are several vessels serving one link, they are often not of uniform size, and some departures may thus have capacity constraints. While drivers may aim for a certain favorable departure, en route delays may hinder this, and the capacity constraint on the unfavorable departure poses another hindrance and further delays.
- Late arrival. An en route delay causes a truck to arrive at a freight terminal after hours. Crew must be called in for loading and unloading of goods. Carrier has to pay overtime for terminal workers.
- Wrong or incomplete documentation. Goods are often not picked up or delivered because driver/carrier/forwarder/terminal operator lacks full information on what is to be picked up or delivered where.

In sum, all carriers had experienced disruptions resulting in consequences for the intended sender of the goods transported. The responses and deliberations given verbally during the interviews also showed that the carriers were acutely aware of their important role in the overall supply chain. While ferry links are perhaps a typical Norwegian problem, and perhaps not found to this degree in other countries, it does show how all elements of the transportation network contribute to the overall performance of the supply chain.

## Mitigative and contingent measures

As earlier noted in the discussion on risk sharing, the carriers are the supply chain element that experience the immediate effects of a transportation disruption, and thus they are also closest to finding measures than can reduce the probability or impact of disruptions. The answers as to what each carrier saw as typical measures varied widely, but some answers occurred more often, such as

- Contingency contracts with companies offering maintenance, repair, rescue or towing services along the most frequently used road links.
- Cooperation agreements with other carriers to secure replacement drivers or replacement vehicles for transferring goods from the broken vehicle to the replacement vehicle.
- Structural and/or technical modifications of vehicles and equipment to improve operations, particular under winter conditions.
- Regular dissemination of information to drivers where to find which roadside assistance..
- Neutral and non-descript packaging to avoid theft of valuable goods.

- Sufficient slack in lead time of scheduled routes in order to account for possible delays.
- Depending on the external circumstances, no guaranteed lead time or arrival time.

Particularly the two first answers were cited as the most important mitigative and contingent measures vis-à-vis transportation disruptions. The last measure, "no guarantees" was often used during winter, or when known road closures along the normal route meant that the truck had to use an alternate route.

# CONCLUSION AND FUTURE RESEARCH

## Summary of findings

The investigation of sources of uncertainty and unreliability in transportation networks and the resulting impact that transportation disruptions have on supply chains is inherently complex and not an easy task to accomplish. While the results of this small study are still inconclusive, we can discern certain trends and patterns:
Manufacturers and transportation-dependent businesses appear to seek vertical integration of a selected freight carrier into their supply chain, and are willing to pay a "risk premium" for securing on-time delivery. The carrier then ensures this delivery for the price given by making appropriate choices within the contractual agreement with the freight owner.
Freight carriers employ various measures, depending on how strong ties they may have to a certain freight owner. Mainly, freight carriers establish a certain contingent flexibility, by which additional resources (e.g. replacement vehicles or repair crews) can be called upon, either from within one's own ranks or in cooperation with other freight carriers. In addition, vehicles are modified and adapted to ensure more reliable operations, particular for winter conditions. Within the freight carrier community we found a general readiness to "help each other out" in times of need.
Transportation disruptions do not appear to be a major concern for transportation-dependent businesses, because both the mitigative and contingent measures are sufficiently handled by the freight carrier. The freight carriers carry the risk of transportation disruptions, not the businesses. Some businesses rely on safety stock or fixed regular deliveries, where the carrier has to follow a time schedule. This ensures delivery, even if it is not needed at that time. Some carriers seek long-term contracts with freight owners, which in turn pave the way for the carrier investing in vehicles and equipment to satisfy the freight owner's requirements as to reliable deliveries.

## Future research

Our selected sample of transportation-dependent businesses and freight carriers has shed some light on how transportation disruptions affect supply chains, and ought to provide a fruitful starting point for further research opportunities. Question that could be asked are:

- Which risk sources can cause transportation disruptions in ingoing or outgoing flows, related to supply and demand and flows internal to the company, and what are the consequences related to supplier, customer and the company itself?
- What risks lead to which consequences and how are they handled or mitigated?
- How do different manufacturing processes (make to stock, make to order, engineer to order) reflect on the risks and consequences?

Figure 8 suggests the framework for such research.

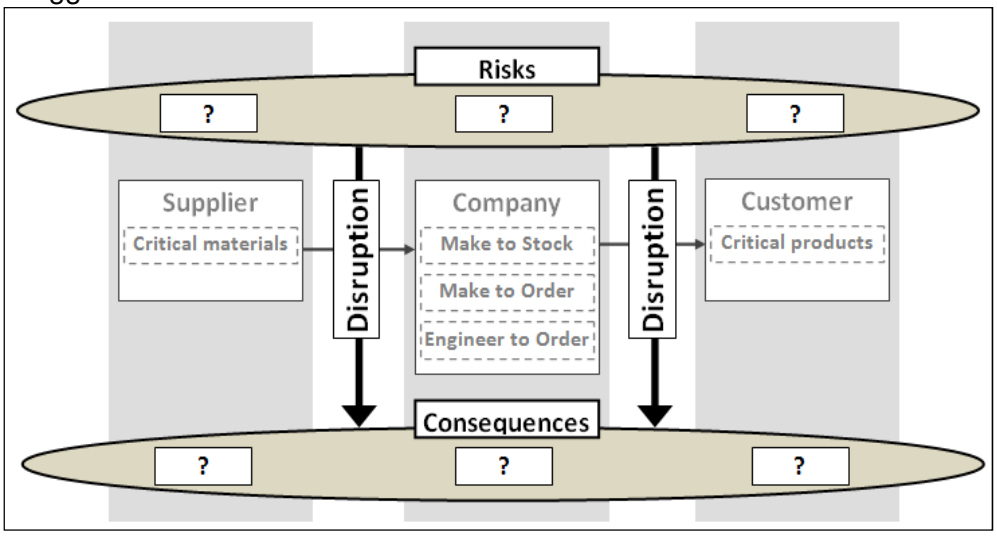


Figure 8 - What risks in the supplier, company, and customer realm lead to which disruptions, and what consequences does this have for the supplier, the company or the customer?

With transportation networks being an integral part of supply chains, transportation disruptions are in turn an integral part of supply chain disruptions. As noted in the above discussion on risk sharing, the carriers are the supply chain element that experience the immediate effects of a transportation disruption, and thus they are also closest to finding measures than can reduce the probability or impact of disruptions. Sanchez-Rodrigues et al. (2008) contends that many of the causes of uncertainty in a supply chain can be linked to who is in charge of planning, organizing, procuring and managing the freight transport operation, thus suggesting the importance of transport operations in he overall supply chain performance. Preparing for disruptions should therefore be an integral part of supply chain risk management. The framework suggested here will hopefully contribute to that.

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