EXPLORING SUPPORT INFRASTRUCTURE FOR FREIGHT TRANSPORT OPERATIONS

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ABSTRACT

Previous publications on freight transport operations have outlined the need for increased effectiveness and better use of information in transport operations. A key to this is the availability and accessibility of information to improve management of the various activities. Improved electronic information sharing reduces the time needed for manually typing data into different systems when handling freight. The technical development that has been taking place over the recent years has created opportunities that can support exchange of information in the freight industry beyond what previously has been possible. Some of these technologies and methods enable increased efficiency and secure information quality.

A holistic approach to combine physical assets with Information- and communication technology (ICT) solutions and systems in order to enable better logistics solutions is the foundation of the Smart Transportation Management (STM) concept. By combining the physical infrastructure (warehouse, terminals, roads, etc.) with a digital infrastructure (ICT solutions), an Intelligent Infrastructure (II) is facilitated. The II could be defined as a support infrastructure, as the purpose is to support freight transport operations in various ways.

This paper starts out by outlining a number of issues and challenges in freight transport operations that were combined and aggregated to create a point of departure for the work. The main purpose of the paper is to explore ICT-enhanced support infrastructures for freight transport operations in the context of Intelligent Freight Transport Systems (IFTS).

The results show that the framework of STM will provide a mapping capability of the subject and an analysis model intended to identify and highlight where and how implementations of STM create valuable impacts on transport operations. These contributions are aimed at the transportation research area in logistics, with a focus on those that are researching information related issues and Intelligent Freight Transport Systems. Physical and digital infrastructure provides support for transport operations through combining the individual functionality and provides the transport industry with new opportunities for improved operations. With such ICS based Intelligent Freight Transport Systems framework that support transport operations it is possible to improve operational excellence within the transportation industry, mainly the road based one.

Keywords: Transportation, Logistics, Digital Infrastructure, Information Systems, Intelligent Freight Transport Systems

INTRODUCTION

The shortcomings of a transportation system can normally be related to three main areas: transport infrastructure, transport planning and operations, and freight handling (Manheim, 1979). Previous research outlines a wide range of deficiencies mainly in transport infrastructure (Rodrigue 1999, Woxenius and Sjöstedt 2003, U.S. Department of Transportation 2005, Alvergren et al. 2008) or transport planning (Dorer and Calisti 2005, McKinnon and Ge 2006, Kalantari 2009). Freight handling has mainly been examined from the perspective of technologies, e.g., port portals (Henesey et al. 2007, Tsamboulas et al. 2007), barcodes or RFID implementations (Boushka et al. 2002, Johansson and Hellström 2007). Other literature has highlighted some opportunities for improvements in the control and handling of freight, e.g., from a complexity perspective (Arnäs, 2007), lean perspective (Brehmer 1999, Sternberg 2012) or security perspective (Ekwall 2009). There is also literature focusing on intelligent infrastructure, but it tends to have a specific focus such as on roads (Hsu and Wallace, 2007) and not a holistic logistics approach.

Previous works on freight transport operations have outlined the need for increased effectiveness and better usage of information in transport operations (Landers et al. 2000, Sternberg 2008a, Kalantari 2009). A key to this is the availability and accessibility of information (Carneiro 2001, Stefansson 2006, Sternberg 2007) to improve management of transport operations. Improved electronic information sharing reduces the time needed for manually typing data into systems when handling freight (Sternberg, 2008a). The technical development which has been taking place for a number of decades has created technologies that can support exchange of information in freight transportation operations (Boushka et al. 2002, Boyson and Corsi 2002).

One holistic approach to combine physical assets with ICT solutions and systems in order to enable better logistics solutions is Smart Transportation Management (STM) (Stefansson and Lumsden 2009). By combining the physical infrastructure (the warehouse and its components) with a digital infrastructure (information systems and technology), an Intelligent Infrastructure is created.

Physical infrastructure is a number of combined supporting resources that allow trucks, ships, trains, airplanes and other types of transportation vehicles to operate. This includes, for example, roads, tunnels, terminals and seaports. These types of resources are necessary to be able to physically move freight from one location to another as well as perform operations such as consolidating goods or temporarily storage.

Digital infrastructure is other type of supporting resource includes information systems and equipment that use, store, generate or modify information related to the freight transportation operations. Information is the cornerstone of efficient freight transportation for a number of reasons, such as knowing what, where, when and how to pick up assignments, transport and deliver freight according to the current situation, known customer demands and terms. Figure 1 illustrates the two pillars of an Intelligent Infrastructure (II).

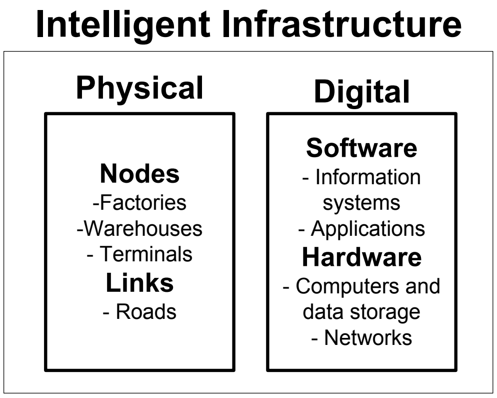

Figure 1 - Some examples of Intelligent Infrastructure components related to road transportation

The II could also be defined as a "support infrastructure," as the purpose it fills is supporting freight transport operations in various ways. All infrastructure components that either actively or passively support the transportation system are considered support infrastructure in the context of this paper.

Increased freight transportation is a growing concern for our society, both from an economical and environmental perspective, (Daniëlle et al. 1999, Woxenius and Sjöstedt 2003, Litman and Burwell 2006). Increased resource utilization is important to enable sustainable and a more advanced and coordinated IT platform is necessary to secure freight transportation (Stefansson and Woxenius 2007, Stefansson and Lumsden 2009,). An Intelligent Infrastructure is suggested to be this enabler. By coupling a physical infrastructure with a digital one, it becomes possible for the infrastructure to communicate with what it is linked to, including freight. Together, the physical and digital infrastructures create an Intelligent Infrastructure.

By applying the II, different participants of freight transport operations are linked together in a digital environment that facilitates and elucidates the interfaces between. By doing so, the Intelligent Infrastructure act as a platform for different kinds of value adding applications and information services for transport operations. This creates new opportunities for collaboration between different organizations and participants in the freight transportation industry. The Intelligent Infrastructure supplies information that has been gathered from, for example, sensors, scanners, cameras, enterprise resource planning systems, databases, and information systems and positioning technologies.

Many challenges surface in transport management related to haulers operations including manage vehicles and drivers, manage the freight flow and customer contacts, and finally, manage of authority contacts (Stefansson and Woxenius 2007). The major characteristics of managing the vehicle and driver are: reducing fuel consumption and maintenance costs, a better overview of driving hours, accessing information about road congestion or other relevant information about the traffic situation, reducing delays, etc. (Wen 2011). The major characteristics of freight flow and customer contacts are: reduce waiting time by providing customers with notification of impending delivery, reduce delivery and invoicing errors, reduce delivery mistakes, improve customer service through real time visibility of arrival and departure and the identification of problems en route (Esper and Williams 2003, Sternberg 2012). The major characteristics of managing authority contacts are reduced paperwork and administration costs, improved driving hours reporting and improved charging feasibility and a common platform for charging policy.

To enable the above benefits, a new infrastructure for data communication must be implemented, not only in warehouses and terminals, but even in vehicles on the road carrying the goods (Spieß et al. 2007). The vehicles and the goods or the load units have to be equipped with communication technologies that indicate position and status of the goods and vehicles. Such technologies enables supply chain operators to react to deviations from schedules and change their plans in accordance to the new situations.

Previous and ongoing research has pointed out that smart transportation needs to be based on three main components: Smart Freight, Smart Trucks and an Smart Infrastructure (Stefansson and Lumsden 2009). An Intelligent Infrastructure implies that a great number of possibilities become possible, attached to a number of big challenges. When designing an Intelligent Infrastructure the ambition should be to satisfy and coordinate the different participants' information requirements (Sternberg 2008b). This is to enable the creation of a more sustainable, efficient and safe transportation system with the help of new types of services and to create business opportunities for the customer and the logistics operators. The value of coordination increases with the closeness to the end customer (Lumsden and Mirzabeiki 2008). This implies the need for advanced freight systems in downstream operations.

Some components of the infrastructure, such as warehouses and terminals, are slowly starting to close the gap when it comes to implementation and integration of information systems and ICT. The investments are no longer as daunting as they used to be, as the tools and applications are cheaper and the know-how is now available to a greater extent. The awareness about the benefits that can be gained from information systems and ICT in this context is beginning to take root in the industry. This leads to a slow but steady improvement across the industry as the benefits are continuously gained in conjunction with various other improvement projects and as new investments are made. Exploring a holistic approach to how these benefits could be achieved in full, and studying if they can provide any synergy in combination with each other is therefore of interest.

A possible point of departure for exploring the holistic II/ICT approach would be to focus on the different issues and inefficiencies that can be found in a warehouse and terminal context, and how they can be amended using ICT. With that as a starting point it is possible to then start focusing on the concept as a whole, and for example begin exploring the decentralization and decision making aspects of transport operations.

This poses some challenges. One such challenge is identifying what the different enabling functions are. Another is finding what the requirements are that would have to be fulfilled in order to develop these visionary ideas and scenarios of how future freight transport operations can be supported by an enhanced infrastructure and other IFTS components. To combine all these issues and challenges and by using the stated point of departure a purpose has been stated:

> *"The purpose of the paper is to explore ICT-enhanced support infrastructure for freight transport operations, in the context of Intelligent Freight Transport Systems."*

RELEVANT LITERATURE ON TRANSPORT MANAGEMENT

More advanced management of transportation has been discussed to great extent in the literature. This discussion is often related to technology advances and standardization. This work has been done in different areas such as IFTS services, freight operations, vehicle, geographical and traffic information, etc. The issue is that these standards have been developed independent from each other. To create comprehensive and standardized IFTS services for freight transports it is necessary to create an information structure that enables integrated information from different areas and participants. In this context the vehicle's connection, and indirectly the freight's, to the Intelligent Infrastructure has a central role. To be able to put such a cohesive information structure together a platform is needed to translate or combine the different types of standardized information.

Smart Transportation Management (STM) is a concept based on decentralized information use, making information available to the participants in the transportation setup. The three main defined components of STM are Smart Freight, Smart Vehicles and Smart Infrastructure (Stefansson and Lumsden 2009). One benefit of using STM is securing information quality and availability in order to avoid costs related to erroneous or missing information. To use STM there are conditions that have to be met in order to gain benefits from the decentralized information setup. According to Lumsden and Stefansson, one such important condition is that there are local units, called enablers, that are able to read and write the item tags and that are able to communicate with other units and infrastructure. The purpose of this is to keep material and information flow in sync in order to provide control. The STM concept suggests the following capabilities of Smart Freight: 1) process a unique identity, 2) be capable of communicating effectively with its environment, 3) retain or store some data about itself, 4) deploy a language to display its features, production requirements, etc., and 4) be capable of supporting local decision making (ibid).

The components of Smart Transportation Management are, as previously mentioned, infrastructure, vehicles and freight. There are three typical hierarchical levels of STM as shown in Figure 2:

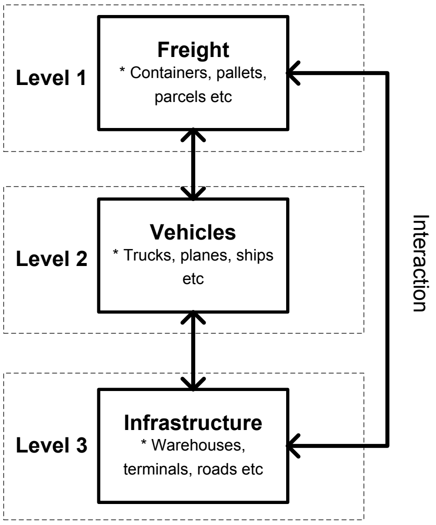

Figure 2 Levels of Smart Transportation Management

These are in different levels of the transport system, and can be affected and improved in very different ways. They are related, interconnected and dependent on each other, but still they are owned, used and managed by different stakeholders in transport operations.

Smart Freight

Smart Freight, Smart Goods, and Smart Cargo are used interchangeably in the literature and are partly synonyms. According to Holmqvist and Stefansson (Holmqvist and Stefansson, 2007), "Smart Goods" is characterized by a higher level of sophistication. This means that instead of using former technologies such as barcodes (to identify an item), it is now possible to furnish the goods, either individual items or the load unit, with new smart technologies, simply by using a modified RFID tag as a carrier of data. Holmqvist and Stefansson (ibid) further introduce and explain several technologies that are combined with each other; among others, RFID, GSM/GRPS and Web Technology (Ghribi and Logrippo, 2000, Kärkkäinen et al., 2003;). When these technologies are combined together and the benefits from each are used, potential to reach maximum performance along with higher data exchange is possible.

Smart freight by itself has many components and relies on many technologies to enable operation. The use of RFID in the supply chain has the potential to provide real benefits in inventory management, asset visibility, and interoperability in an end-to-end integrated environment (Vaughan 2003, Ustundag and Tanyas 2009, Prater et al. 2005, Twist, 2005, Jones et al. 2005). By using RFID and other identification technologies supply chain visibility can be obtained (Lapide 2004).

Smart Vehicle

A major issue in the STM system framework is the so-called Smart Vehicle. For this work, mainly distribution vehicles or trucks are in focus where the truck cabin is equipped with a vehicle computer system and identification of goods is done as freight is loaded or unloaded off the vehicle. Communication of this information to central systems is not necessarily carried out; in many cases the information is only stored in the vehicle computer system and in other instances the information is communicated to a central information system, especially if deviations occur or a pre-notification of arrival is needed.

Considering that information about the freight is captured while loading the vehicle and that the manifest is downloaded to the in-vehicle computer gives the following:

- The possibility to minimize the risk of loading/unloading the wrong freight
- Helps to load/unload in the right sequence
- Makes it more visible to know how many assets are used in the system
- POD and POA can be sent to the host system in real time

With such a solution, a link is established between the vehicle and the goods, something that is not seen in many operational systems today although exceptions occur.

Smart Infrastructure

To complete the concept of STM, Smart infrastructure needs to be introduced. Smart Infrastructure can be divided into two parts: *digital* and *physical*. It is important to distinguish between these two, as they are so different in characteristics.
Physical infrastructure is not only the roads and bridges vehicles travel on. It consists of:

- Roads
- Tunnels
- Ferries
- Ports
- Warehouses
- Terminals and similar asset based facilities.

Toward this physical Smart infrastructure, Smart Vehicles can have two-way information flow through the ICT systems that are part of the digital infrastructure. In this way the vehicle is connected at all times, providing real time information as needed.

The smart digital infrastructure retrieves, manipulates, stores and communicates data and information from the physical infrastructure to and from the Smart vehicles using different digital technologies such as sensors, cameras, databases, and positioning technologies. The Smart infrastructure enables information exchange about the goods, vehicles and infrastructure to be transmitted between participants as needed (Jones et al. 2005; Alvergren et al. 2007).

The reason for this is that there is no common standard or definition of how a smart infrastructure should be designed or built. However, there have been efforts to describe how a possible smart infrastructure could be designed. Spieß et al. (2007) have focused on identifying and explaining the technical requirements of a holistic “Smart items infrastructure” (SII). With a service oriented architecture (SOA) they suggest a more flexible and adaptable infrastructure for ubiquitous computing. This SII cannot only fulfill current and future demands on Auto-ID, but also scale to provide a foundation for the next generation of smart items. This includes items with locally embedded units with processing power. Many of the components in the proposed SII are of interest in the context of digital infrastructures, and can be used as examples. They are especially relevant in terminal and warehouse operations as they enable tracking and tracing and other benefits for in house movement of items and shipments. Additionally, the article by Spieß et al. (ibid) is used to define some terminological definitions, such as decentralization.

Decentralization is a very important part of the entire Smart infrastructure concept, and this also applies to the Smart items infrastructure. Some of the benefits according to Spieß et al. (ibid) include scalability, improved data accuracy and response times. Through the decentralization and implementation of more units with processing power the reliance on centralized databases and backend systems decreases, and overall system performance is assumed to increase and become more reliable. Some of its strength lies in being able to utilize currently used technology such as RFID while being open to and providing architecture that supports the next generation of technology, at the same time using open system architectures. Yet another proposed decentralized Smart infrastructure architecture is the vehicle-to-vehicle-to-infrastructure (V2V2I) hybrid architecture (Miller, 2008). Miller (2008) proposed two architectures, vehicle-to-vehicle (V2V) and a vehicle-to-infrastructures (V2I), and in this combines the two in order to reap the benefits of both.

METHODOLOGY

The general approach in preparing this paper has been to apply qualitative methodology. According to Croom in Karlsson (2009), qualitative methods are used to “recognize and attempt to account for the significance of interpretation, perception and interaction in the process of defining, collecting and analyzing research evidence.” The methodology is a result of the choices made by the researchers when designing and planning the research. It is necessary to elucidate the process and employ a research process that is viable, reliable and valid. To ensure reliability of the results, following the same research procedure, documentation of the research process is crucial (Yin, 2003). The qualitative case studies were carried out using case study protocols and a case study database.

Eisenhardt (1989) believes that cases should be chosen so that they are likely to replicate or extend the emergent theory, or they should be, according to Arbnor and Bjerke (1996), versatile and interesting. Case studies must utilize both internal and external validation to ensure the integrity of the study. The verification and validation of the collected data in the studies were iterative processes that were carried out based on Chung’s theories (2003) and

Bank's methods (2001). The data was collected in many steps. After each revision, the data was reviewed by the interviewees to make sure it was a correct depiction.

According to Yin (2003), the external validity problem has been a major barrier in doing case studies. Some critics have stated that single case studies make a poor foundation for general examples. However, it is important to consider that this criticism is based on comparisons of generalization between case studies and surveys. The important difference is that surveys rely on statistical generalization while case studies rely on analytic generalization. The purpose of generalizing this case study is not to provide the perfect example, but rather to provide a good example of a typical setup. In order to do so it was of importance to present the gathered data in a neutral format while still being accurate and providing a valid

Empirical Data collection

The empirical data used in this work comes from four studies in total having different purposes and different scopes. Study 1 focused on a supplier's infrastructure. Study 2 expanded the scope to include the supplier, transportation in between and the distribution terminal(s). The third study included supplier, transport operations, distribution and customer. Finally, the fourth study, focused on the various requirements that need to be fulfilled in order to progress toward transport operations that utilizes IFTS and ICT to a greater extent than contemporary operations.

Yin (2003) presents four tests to assess the quality of case study research: construct validity; internal validity; external validity and reliability. During the data collection all these four tests have been used to ensure case study research quality. When collecting data multiple sources of evidence have been used, converging the evidence into the same set of findings. Case study protocols and case study databases have been used during data collection. In the case studies key informants have reviewed the case study reports. The raw materials have been coded and categorized in order for patterns to be identified.

The verification and validation of the mappings of the studied processes was an iterative process. The mapping was done in many steps. The first step is starting with a rough depiction and slowly turning it into an extensive mapping of a process. Each process was completed one at the time, and after each revision it was reviewed by everyone involved in the process, from managers to floor workers, to make sure it was valid. Once there was nothing more to change in the process mappings they were deemed a correct depiction of the actual process. The next step was then to integrate the various processes into a complete depiction of the system. Figure 3 illustrates this:

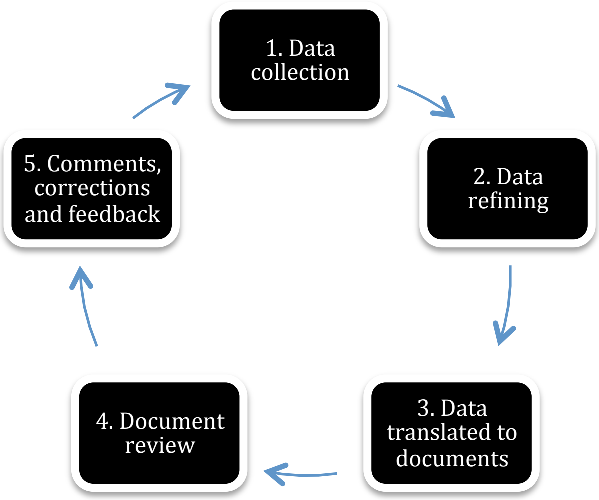

Figure 3 - An overview of the data collection process

Overview of the four studies are given below.

Study #1 - Warehouse study

The first case study was carried out at a large Swedish electric component distribution company and is an in depth study of the warehouse process. The case study was mainly chosen due to the opportunity of being able to perform an in-depth study of a warehouse with complex processes and activities. Another major reason for choosing the specific case was the openness and trust in the researchers the staff of the company showed, allowing complete access to all staff, documents, databases and other resources.

It depicts all the different activities and specific information and data used every step of the way for items, from delivery to placement on a warehouse shelf. The data was collected by the author together with another researcher over a period of one year; the author mainly collected data during an intensive period of 5 months of which a lot of time was spent at the warehouse, and the colleague collected data while visiting the warehouse frequently for more than a year. This data would later be complemented by further studies of the same system, by expanding the boundaries of the system to include the transport vehicle and freight handling terminal.

All six sources of data mentioned by Yin (2003) were used in this study (documentation, interviews, archival records, direct observation, participant observation and physical artifact). The process mapping was conducted in many steps, starting with a rough depiction and slowly being tuned into an extensive mapping of everything involved in the inbound process. After each revision it was reviewed by everyone involved in the process of creating it, from the logistics manager to floor workers, to make sure it was correct. Once there was nothing more to change in the mapping, it was finally deemed a correct depiction of the actual process.

Study #2 - Freight study

Data was collected through a series of interviews, video filming of the complete processes, document studies and active observations. The approach for this study is twofold: firstly, to support the analysis of the primary data, relevant literature on logistics, green logistics and information science has been reviewed; and secondly, empirical data has been collected from a dual case study.

The two case studies were carried out through open observations and interviews, both structured and semi-structured within each case. In total, 70 interviewees were chosen from both operations and management, 43 in case study 1 and 27 in case study 2, to achieve a full picture of the studied transport setups. This led to a lot of duplicate information and several interviews did not present any new insight but increased the accuracy and reliability of the findings. All the questions from the structured interviews as well as the notes from the semi-structured interviews have been saved. Copies of all documents circulating in the flow were obtained.

The notes collected from the interviewees were compared and followed up for validity and reliability. The complete findings of the case study were published in a requirements report and were validated by both the responsible LSP (Logistics Service Provider) as well as one carrier. The findings were also validated against the findings of another information mapping study carried out by Nyquist (2007). Some results from the same project were published in Sternberg (2008).

Study #3 - Smart Transportation Management functions study

The empirical data was collected through interviews with various organizations that somehow are linked to the relevant areas. These include infrastructure providers, transport operators, truck manufacturers, software providers, shippers, logistics service providers and more.

A system approach has been applied where not only was it important to understand the system components but also the relations between the components. To be able to do so, the components were studied in their natural relation to each other and not only in their causal relations (Arbnor and Bjerke, 1997).

Studying the smart freight included mainly secondary data as a lot of evidence can be found in the literature on automatic identification, RFID, decentralization of information, etc.
For the Smart vehicle study, both truck manufacturers and suppliers of advanced transportation management were studied. The systems embedded in trucks today were considered and the providers of such systems, including one of the major truck manufacturers in Sweden was included in the study. The vehicle information system providers were studied and the information systems they supply reviewed. This included a major Swedish provider of transport management and fleet management systems.

Finally, the study of infrastructure included the road administration in Sweden as well as users of the infrastructure such as transport operators and logistics service providers.

The case studies that were carried out were in all instances carried out by interviews, using a semi structured interview template, with managers in higher levels of operation. In addition, documentation was reviewed and when possible, direct observation was done to accomplish data triangulation (Yin, 1994). The reason for choosing the semi-structured configuration was to increase the coherence between the interviews and to make a within-case analysis easier (Eisenhardt, 1989).

Study #4 - Infrastructure study

Empirical data was initially collected through a pre-study of semi-structured interviews with 6 experts. These experts are either scholars or industry professionals and they provided a starting point, from both an academic and industrial point of view, for identifying different types of requirements. In addition, documentation was reviewed and when possible, direct observation was done to accomplish data triangulation (Yin 1994).

This material was then used to start discussions about their potential effects in a workshop with 16 experts (a mix of scholars and industry professionals) within the transportation field and in the ICT field (related to transport operations). A system approach was applied where not only was it important to understand the system components but also the relations between the components. To be able to do so, the components were studied in their natural relation to each other and not only in their causal relations (Arbnor and Bjerke, 1997). The reason for choosing the semi-structured configuration was to increase the coherence between the interviews and make a within-case analysis easier (Eisenhardt, 1989).

The analysis of the requirements and effects was conducted mainly using the primary data collected. However, secondary data sources that were found in the literature also provided some valuable input as they covered some additional perspectives that were not covered by the expert group in the study conducted for this paper. The secondary data sources have been used to provide additional evidence or to complement the dataset to provide a more complete picture.

CASE STUDIES ANALYSIS

The results of Study 1 and 2 highlight the weaknesses in today's control of transport operations and present a model for how Smart Cargo enables a more environmentally friendly and accountable transport system. The main managerial implication is the demonstration of the feasibility of Smart Cargo as an enabler of improved environmental and financial sustainability. Another aspect is the confirmation of the theory from other authors that environmental efficiency goes hand in hand with resource efficiency. The theoretical implications identifies how the concept of Smart Cargo and using decentralized information in transportation can benefit both environmental and financial sustainability as well as enable transport systems with environmentally accountable shipments. Several of the delimitations that have been identified that can be considered interesting for future research, especially research on logistics models creating incentives for environmentally effective transports. Additionally, the outline of the transport processes shows how it can be improved by decentralizing decision-making. It also outlines the capabilities of Smart Cargo and how it can enable control and decentralized decision-making in transportation. There are implications outlining the areas of future improvement in freight transport operations. This can serve as an initial guideline for investments and initiatives to improve transportation.

The third study identifies the functionality of Intelligent Infrastructure within a STM setup. The various functions provided by Intelligent Infrastructure are found to be very useful for many areas of transport operations such as automatic identification, dynamic routing, road charging, and more. The study also identifies the functionality of Intelligent Infrastructure and is useful when analyzing the effects of these functions on transportation operation, including environmental impacts. Practical implications are based on the capability of identifying the functionality and potential effects of possible investments made in advanced technology related to freight, vehicle and infrastructure on transport operation. The effect of different functionality of Intelligent Infrastructure is often difficult to estimate and has to have its point of departure in identifying the functionality. The originality of this research is based on a structure that can be used to analyze the various functions, and based on that, further work on the effects that can be expected.

Furthermore, the fourth and final study findings are a number of requirements (and their effects) that are necessary for moving toward a realistic IFTS and ICT scenario in future transport operations. For example, data availability has been shown to be the number one requirement for building a future digital infrastructure when gathering requirements for freight ICT and IFTS systems. This may also provide some insight into which aspects should be taken into consideration when working with improving transport operations and having future technology and concepts in mind. Identifying the requirements of a future digital infrastructure and their possible effects has not previously been done and can be of value to other researchers in the field. It may also be of value to those working with transport operations on a strategic level as it can provide limited insight about future trends.

The various findings have been compiled and are summarized to provide an overview in the table below:

Table 1 Summary of study findings

	Purpose of the study	**Findings**
Study 1	Explore opportunities for enabling effective and decentralized decision making in freight transport operations and bridging the gap between physical and digital infrastructure.	Outline of Smart Cargo capabilities in conjunction with Infrastructure and how it enables control and decentralized decision making in transport operations.
Study 2	Explore freight transport operations to identify possible impacts that applied IFTS and ICT could have with freight as the focal points for decentralization and improving decision making from a sustainability perspective.	Highlights the weaknesses in contemporary control of transport operations and presents a model for how Smart Cargo enables a more environmentally friendly and accountable transport system. Demonstrates the feasibility of Smart Cargo as an enabler of improved environmental and financial sustainability, and confirms the theory from other authors that environmental efficiency goes hand in hand with resource efficiency.
Study 3	Identify and analyze the functions of the Intelligent Infrastructure component of STM setups, in the context of transport operations and its consequential environmental impacts.	Identifies the functionality of Intelligent Infrastructure within a STM setup and the various functions provided. It is useful for analyzing the effects of these functions on transportation operation, including environmental impacts. It aids in identifying the functionality and potential effects of possible investments made in advanced technology related to freight, vehicle and infrastructure on transport operation.
Study 4	Identify the requirements of a future digital infrastructure based on IFTS and ICT, and highlight the potential effects these requirements could have on transport operations.	The findings are a number of requirements (and their effects) that are necessary for moving toward a realistic IFTS and ICT scenario in future transport operations. The paper may also provide some insight into which aspects should be taken into consideration when working with improving transport operations and having future technology and concepts in mind.

SUMMARY OF RESULTS

This paper started out by outlining a number of issues and challenges in freight transport operations. These were combined and aggregated to create a point of departure, and a purpose. The purpose was broken down and divided into four different research focus areas: 1) Infrastructure interactions; 2) Decentralization and decision making; 3) Infrastructure functions; and 4) Requirements and effects.

Together, these four different parts of the purpose fulfill it in its entirety. Their combined findings and contributions paint a picture of what an Intelligent Infrastructure for freight transport operations is in an Intelligent Transport System context, and subsequently how it affects the operations.

Infrastructure interactions

The first part of the purpose, *infrastructure interactions*, has been fulfilled by theoretically implicating and outlining how freight transport operations can be improved by enabling capabilities of Smart Cargo interacting with an Intelligent Infrastructure. Also implied are practical contributions of how future improvements to freight operations could be implemented, and it provides initial guidelines for what possible investments and initiatives can be made in order to create those improvements.

Several areas of the handling process were identified and how effectiveness could be improved through implementation of the smart freight concept. Solutions based on Smart Transportation Management and Smart Cargo that were applied in this context imply that almost every single action conducted in the handling process of this transport setup could in some way be improved or enhanced by using information systems and technology. These findings show that it is of importance to consider all aspects of the process when attempting to identify areas to improve.

The terminals in the studied transportation operation are not showing the same need for improvement of effectiveness as central terminals/warehouses, depending on the extent of the Smart Cargo implementation in the central terminals/warehouses. This can be seen as an effect of how properly planned, packed and consolidated shipments sent to the terminal can make handling easier upstream. The result is that the terminal generally only needs to move shipments from one truck to another, without any additional activities involved. Improvement for logistics service providers at terminals seems to be more in the area of planning of transport flows than how handling of freight is conducted. Minor improvements are possible, however, but the benefits are much harder to identify.

In short, by implementing information systems and technology based on the ideas of Smart Transportation Management in warehouse and terminal operations, it can become a part of an Intelligent Infrastructure.

Decentralization and decision making

The second part of the purpose, *decentralization and decision making*, has been fulfilled by theoretically demonstrating the feasibility of the Smart Cargo concept and how it can enable sustainable freight transportation operations. The current lack of control in freight transport operations causes inefficiencies and unnecessarily strains the environment. Operational and environmental efficiency go hand in hand, and decentralization caused by STM components on a practical level could create benefits.

Applying the concept of Smart Cargo and using decentralized information in transportation can benefit both environmental and financial sustainability. Also, that it can enable environmentally accountable shipments in transport systems. The study highlights some of the weaknesses in today's control of transport operations, and the result is that Smart Cargo can enable a more environmentally sustainable and accountable transport system.

The consumers of transport services are voicing demands for ecological accountability. The so-called ecological foot printing (also known as carbon foot printing) is the recording of the emissions of every movement, transportation work, of the freight. Previous research has shown that transport planning, system integration and control are some of the key factors to achieve more sustainable transport setups. Smart Cargo is a holistic concept, integrating transport management and state-of-the-art technologies for freight tracking and vehicle monitoring, in order to enable improved management and accountability of freight transportation. Because of the capabilities that STM enables it is possible to decentralize information, which in turn makes it possible to decentralize decision making. This means that the process of decision making in logistics operations can be improved, as the reliance on centrally controlled functions decreases, or is removed entirely.

Infrastructure functions

The third part of the purpose, *infrastructure functions*, has been fulfilled on a theoretical level by identifying a number of functions of an Intelligent Infrastructure. These functions are useful and beneficial (i.e., environmental sustainability) on a practical level. Identifying these functions is helpful for analyzing which effects could be caused by utilizing an Intelligent Infrastructure.

The third focus area is providing a descriptive framework of the STM components and the functions made possible by the Intelligent concepts. These functions have been divided into three different areas: operational (economic), environmental and safety(social)/security. The reason for doing this was to identify and analyze the functionality of the Intelligent Infrastructure component of STM setups. This was done in the context of transport operations.

The focus made it possible to identify the functionality of Intelligent Infrastructure within a STM setup. The various functions provided by Intelligent Infrastructure were found to be very useful for many areas of transport operations such as automatic identification, dynamic routing, road charging, and more. The study also identified the functionality of Intelligent Infrastructure and is useful when analyzing the effects of these functions on transportation operation, including environmental impacts.

The effects of the different functionalities of Intelligent Infrastructure have been difficult to estimate, and has to have its point of departure in identifying the functionality. The result is a structure that can be used to analyze the various functions, and based on that, in the future help identify the effects that can be caused by Intelligent Infrastructure. Some practical implications are the capability of identifying the functionality and potential effects of possible investments made in advanced technology related to freight, vehicle and infrastructure on transport operations.

Requirements and effects

The fourth part of the purpose, *requirements and effects*, has been fulfilled in two segments. The first segment was fulfilled by identifying the theoretical requirements of a future digital infrastructure based on Intelligent Freight Transport Systems (IFTS) and information and communication technology (ICT). The second segment was fulfilled by highlighting the possible practical effects these requirements could have on transport operations. The results provide some insight into which aspects should be taken into consideration when working with improving transport operations and having future technology and concepts in mind.

This focus area aimed to identify the requirements of a future digital infrastructure based on IFTS and ICT, and to highlight the potential effects these requirements could have on transport operations. The focus gave results that provided some insight into which aspects should be taken into consideration when working with improving transport operations and having future technology and concepts in mind.

The findings include a number of requirements (and their possible effects) that are considered necessary for moving toward a realistic IFTS and ICT scenario in future transport operations. To exemplify some of these requirements, data availability has been shown to be the number one requirement for building a future digital infrastructure when gathering requirements for freight ICT and IFTS systems. Other important requirements include how transport operations are designed, planned and conducted, the importance of adopting a paperless documentation approach, and increasing automation of activities in transport operations, to mention a few.

CONCLUSIONS

Physical and digital assets that provide support for transport operations through their individual functions should be grouped together. By grouping them together it is possible to form a holistic concept to support transport operations. By themselves the physical assets would only be considered "infrastructure" in a traditional sense. The digital assets on the other hand would likely only be thought of as a number of various independent systems (ICT) and applications that can provide limited benefit to the freight transport operations.

The key to unlocking the potential of synergetic benefits is combining and unifying all the physical and digital assets; to stop considering them individually as nuts and bolts, and instead think of them as pieces of a complex machine. If a holistic approach is taken then these pieces of machinery match each other well, and can work effectively together. As one they not only provide infrastructure but provide a *support infrastructure*. One way to label this type of holistic infrastructure is on a conceptual level, an Intelligent Infrastructure.

There are many issues related to actually forming such a unified support infrastructure. Much work would have to be put into slowly transforming the contemporary fragmented reality into this visionary concept. All the different actors in the transport operations (and possibly also many outside it) would have to integrate themselves more closely to each other than they currently are (if at all). For this to happen one important thing would be implementing standards and creating a unified structure for how the numerous individual organizations and systems interact with each other. Because of the complex situation in the industry this would have to be incrementally introduced, as completely changing the landscape of the industry in one sweeping move is unrealistic at best. The general process in the industry as a whole could be divided into different sub-areas and contexts to be conquered one by one.

The implications of the paper are intended to be useable by both researchers and practitioners. From an academic perspective it is intended for the theoretical gaps to be highlighted in order to provide a point of departure for current and future studies on the subject. The framework of STM projects will provide a mapping of the subject, and an analysis model is intended to identify and highlight where and how implementations of STM create functions. These contributions are aimed at the transportation research area in logistics, with a focus on those that are researching information related issues and IFTS.

From the practitioners' perspective it will be a good starting point for identifying what the various components of STM are and what their functions in transportation setups are in order to evaluate possible future improvement initiatives.

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