



Research Outlook on a Mixed Model Transportation Network

Joakim Kalantari^{1*}, Henrik Sternberg

¹ *Division of Logistics and Transportation, Chalmers University of Technology, Göteborg, Sweden*

Abstract

The purpose of this paper is to present an outlook on the future research for a specific mixed model transportation network referred to as Foliated Transportation Networks (FTN). FTN is thus far a conceptual model that is based on the idea of foliating a direct shipment and a hub-and-spoke structure in order to achieve higher fill rates without an increase in the total traffic work at the same time. The conclusion is that the two principal areas of research are areas of planability (i.e., the ability to in advance and on a sufficient level of detail and precision determine the capacity requirements of the system) and network optimization (i.e., the optimization of the distribution of goods and resources between the different layers of the network).

Keywords: Foliated transportation networks, Mixed model transportation, Transport, Transport planning and control, Transport network optimization.

1. Introduction

Looking at the road bound freight transportation industry; one will quickly encounter a system wide overcapacity and low utilization rates regarding load capacity of the transportation units, i.e., low technical efficiency. Previous research indicates a normal system fill rate span of 50-70% (Caputo et al., 2005, Nanos-Pino et al., 2005).

The technical inefficiencies in the road bound transportation systems have significant negative external effects, making efficient use of the physical resources an interest for society as a whole. Trucks and trailers impact the environment negatively both in terms of pollution (e.g., CO₂ emissions, air and water pollution, etc.) and in terms of noise pollution, congestion and traffic hazards (Kreutzberger et al., 2003, McKinnon, 1994).

The steady past and projected growth of the transportation demand (European Commission, 2003) amplifies the significance of this issue especially in light of the fact

* Corresponding author: Joakim Kalantari (joakim.kalantari@chalmers.se)

that historically, the growth has not been absorbed by the existing overcapacity (Rodrigue, 1999). This observation suggests that the transportation system structures are constructed in a way so that they require or are benefited by maintaining an extensive overcapacity. This development is critically alarming because what the resource overcapacity aims to satisfy is being disabled due to the predictable near saturation of the infrastructural capacity (Crainic et al., 2004).

Efficiency of transport networks is dependent on effective planning (Acharajee, 2000, Landers et al., 2000, Closs et al., 2005) and the alarming background calls for new ways of operating transport networks. Considering the substantial improvement potential that exists, due to the low utilization rates this matter is highly interesting from both societal and industrial perspectives. Changing cost structures due to the rapid development of energy prices and political sanctions as an attempt to dampen the transport sector's negative environmental impact also heavily contribute to the growing need for increased efficiency along with improved or at least sustained performance (McKinnon, 1995, McKinnon and Ge, 2006).

A conceptual model that attempts to address these concerns is Foliated Transportation Networks (FTN). The purpose of the concept is to improve the technical efficiency of the transportation system, i.e., resource utilization regarding loading capacity without the deterioration of other quality or performance parameters. The conceptual model of foliated transportation networks (FTN) is a hybrid model that aims to improve the efficiency of a transportation system by combining the two predominant network structures, i.e., direct shipment (DS) and hub and spoke (HS). It is stipulated that by foliating the two structures (i.e., DS and HS), and by dynamically planning, controlling and optimizing the distribution of goods and resources between the two sub structures, strengths of the individual setup will be amplified at the same time as their weaknesses diminish, resulting in better system performance than any single one on its own (Persson, 2006b, Persson and Waidringer, 2006). In other words, the physical resource utilization will be increased without the deterioration of the other key performance measures such as total traffic work, number of resources in the system, lead time, flexibility, etc.

The purpose of this paper is to presents a research road map for developing the concept of FTN¹ to an operational model. The road map contains both an overview of the empirical as well as theoretical gaps that need to be filled in order to establish the concept of FTN. The contribution of this paper outlines the current status of the research and identifies the necessary research areas for accomplishing an implementation of FTN. The research on FTN takes the perspective of the transportation service provider and regards general cargo freight.

Based on the description above, several principal problems will be posed in contrast to the existing systems. These issues need necessarily be identified and resolved before it is feasible to consider the model operational. This paper aims to identify these gaps.

¹ Going forward, "the hypothetical model of foliated transportation network" will simply be referred to as FTN or variations of the same.

2. Methodology

Preparation of this paper involved a literature study and collection of empirical data. The literature study uses secondary sources such as books, the Internet and scientific articles within the areas of logistics and transportation, information science, mathematics and transportation planning and control. The empirical data employed is qualitative and has been collected via semi-structured interviews and observation. Two major terminals have been visited and personnel from senior management to individual operators have been interviewed. The interviewees have been selected through a process of “snowballing”, where each new interview reveals the need, identifies the interviewee and creates access to the next one.

This research takes an exploratory approach to outline the research outlook for FTN. This is done by systematic combining, i.e., combining inductive and deductive methods (Dubois and Gadde, 2002).

The process of identifying and analyzing researchable gaps for the FTN considered the following factors:

- No real world implementation of the concept available
- The inherent complexity of the studied phenomena (transport networks) (Manheim, 1979, Nilsson, 2005, Waidringer, 2001)
- Sparse literature on the concept (Persson and Lumsden 2006)
- The interdisciplinary nature of the concept, e.g., logistics and transportation, mathematics, operations research and informatics (Persson and Waidringer, 2006)

These factors led to an iterative process, consisting of the three interrelated research components: theory (literature study), empirical area (empirical data collection) and researchable gaps (analysis). This approach is similar to the so called “whirl-pool approach,” which has been successfully applied in areas such as computer science and information systems (Williams, 1996, Trivisano, 1996).

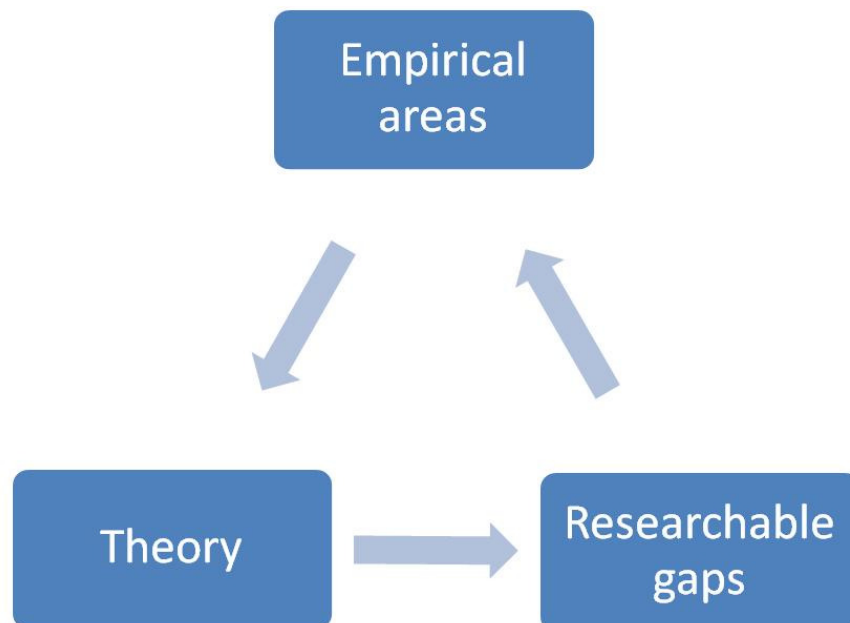


Figure 1: Illustration of the iterative whirlpool process carried out for the project.

The problems from the empirical area generated the initial literature studies. The concept applied to the empirical area generated researchable gaps, which in turn gave indications for additional theoretical areas. As illustrated in (Figure 1), several iterations were carried out before the researchable gaps and were summarized and categorized into the resulting research outlook.

Semi-structured data collection interviews have been performed with senior managers, sales representatives, information system officers, terminal managers and operations managers. Floor operatives, planners and individual haulers have also been interviewed. The need for additional data gradually arose during the iterative course of consulting the existing theory, collecting empirical evidence and submitting the thus-far results of the analysis to formal evaluating seminars. This process was repeated until saturation was reached (Flick, 2006).

The Swedish domestic general cargo freight transportation market is dominated by a two large companies, each covering the entire country through their own network (Sommar and Woxenius, 2007). This considerably narrows the choice of where to collect empirical data, seeing how FTN is only applicable for large networks carrying an abundance of cargo. In the choice of which company's transport network to use as empirical starting point, the most important factor was that the studied network should meet the *representative rationale* (Yin, 2003). The objective of the representative case is to capture the circumstances and conditions of an everyday or commonplace situation. According to Yin (2003): "The case study may represent a typical project among many different projects, a manufacturing firm believed to be typical of many other manufacturing firms in the same industry, a typical urban neighborhood, or a representative school, as examples. The lessons learned from these cases are assumed to be informative about the experiences of the average person or institution."

The actual company chosen has been used by other studies for validation purposes (Stefansson, 2006, Sternberg, 2008a), which is a factor supporting the *representativeness* of the empirical data. For a full account, please refer to the reference case description.

In order to bring additional validity to the results of this study, the identified research gaps have been discussed, revised and finalized through a series of eight formal seminars. The participants of these seminars have been transportation practitioners and research professionals as well as researchers of other neighboring disciplines such as traffic, logistics and supply chain management. The results, presented in this paper, have been finalized after being put to academic scrutiny i.e. defended against a senior and a junior opponent, in a final seminar.

3. Theory of FTN and related areas

The purpose of the theory chapter is to put the concept into a transportation context, outline previous research, describe related concepts and present the theories related to the gaps identified.

3.1. Transport operations management

Transportation is normally associated with the movement of a product from one node in the distribution channel to another. In transportation, attempts are made to solve this problem by ensuring that products are moved as quickly, cost-effectively and consistently as possible from the point of origin to the point of consumption (Ross, 1996).

The transportation network consists of nodes and physical links. Links correspond to highways, rail tracks, seaways or urban streets and nodes express the connectivity relations of links in the network, e.g., warehouses, distribution centers, freight terminals and ports (Manheim, 1979). There are many individuals, groups and organizations whose decisions interact to affect the transportation system and thus the pattern of flows. The user of the transportation, i.e., a shipper of goods, makes a decision about when, where, and whether the goods should be transported and how often (Manheim, 1979).

Options or decision variables are those aspects of the transportation system that can be directly changed by the decisions of one or several individuals or organizations. Manheim (1979) outlines possible options when it comes to transportation system operating policies. This set of options includes the full spectrum of decisions about how the transportation system is operated. The networks, links, and vehicles establish an envelope of possibilities; within that envelope a large variety of detailed operating decisions must be made. These options include vehicle routes and schedules, types of services to be offered, including services auxiliary to transportation (diversion and reconsignment privileges for freight), and regulatory decisions. A *transportation setup* is a set of decisions based on options available for a certain flow of goods.

In general, transport operations management concerns five corner stones and their interrelations. These five are (Brehmer, 1999):

- the capacity of the studied system and its resources
- the average time required for each activity
- the coordination of the resources and the activities
- the inventory, and finally
- the control of activities

A key enabler of effective transport operations management is having necessary information available (Landers et al., 2000). Every setup requires exchange of information between all the involved participants in order to avoid execution hurdles (Sternberg, 2008a).

A good shipped in the system is typically heterogeneous, i.e., loading and unloading procedures varies from shipment to shipment. Arnäs (2007) defines heterogeneity as: "... goods where one or more of the parameters Density (D), Stowability (W), Ease of handling (H) or Liability (L) are outside of their accepted range." In this case it means that a majority of the goods is not fit to be placed, or simply is not placed, on standardized load units or the goods do not offer standardized interfaces for handling.

3.2 Foliated transportation networks

In a transportation network based on the principle of direct shipment every terminal (i.e., node) in the network is connected to all the other ones via direct relations (i.e., link) (Manheim, 1979). This means that dedicated trucks traffic the relation without any

other consolidation stops. In an (from the operator perspective) ideal setup, there will exist a set latest time for accepting new orders. Placed orders will be collected by milk-runs and delivered to the nearest terminal for consolidation and transshipment. All the goods with the same destination will be sorted out and loaded onto long haul trucks in order to be delivered to the destination terminal where they will be sorted and distributed to their final destination, i.e., to the individual consignees.

In contrast to the DS setup where every origin/destination pair of terminals are interconnected through direct relation, in a HS setup all the terminals only have a direct relation to the/a hub. A network can consist of a single hub where all the terminals are connected or multiple hubs where every hub has a direct relation with a cluster of terminals in its vicinity and all the other hubs in the system. The difference between a single and multi-hub setup is the additional consolidation/deconsolidation step that the inter-hub transports imply. In the following presentation a single hub setup is assumed for reasons of simplicity.

When the goods are collected from the consigners, in a HS setup, and delivered to the origin terminal the consolidation process is performed irrespective of the final destination. All the goods from every terminal are then delivered to the hub, where the goods are sorted according to their destination.

However, generally DS and HS are considered each other's opposites. Where DS affords quick and easy to control transports with minimum transport work at the cost of the system wide fill rate of the trucks, the increased number of trucks, and dependence on large volumes of goods in every direction (Crainic, 2002), HS is the exact opposite (Kalantari and Lumsden, 2007). In a HS setup the goods never travel the shortest way, yielding a longer transit time, more handling and more transport work, instead resulting in fewer trucks necessary, higher fill rates and less dependence on big volumes in the system (Kalantari and Lumsden, 2007, Lumsden et al., 1999).

The principle of FTN, where the two structures are foliated, is meant to roughly lead to the following procedure/structure. Every terminal in this setup is interconnected with direct relations. This implies of course that the ability for direct deliveries and hub consolidations are not restricted.² After the initial collection milk-run, all the goods with the same destination that collectively fill whole units (i.e., trucks or semitrailers, etc.) are sent through direct relations i.e. according to the DS principle. All the remaining goods (i.e., goods that do not have the sufficient combined volume to fill a whole unit in a DS relation), in this context defined as "overhang" (Persson, 2006a), are sent to the hub for consolidation (see Figure 2). The conceptual assertion is that the aggregation at the hub will contribute to first diminishing some of the negative traits of DS as well as improving the physical performance by introducing the positive qualities of HS on the remaining volumes or the overhang (Persson and Lumsden 2006, Persson and Waidringer, 2006). When viewed in isolation, the different categories of goods are theoretically well suited for the different network layers that they are meant to travel through, which gives the concept some additional strength (Hultkrantz, 1999, Kalantari and Lumsden, 2007).

² This, of course, assumes that all terminals are unrestricted in capacity. In reality, not every terminal is suited to be selected as a hub, both due to capacity constraints and geographical location.

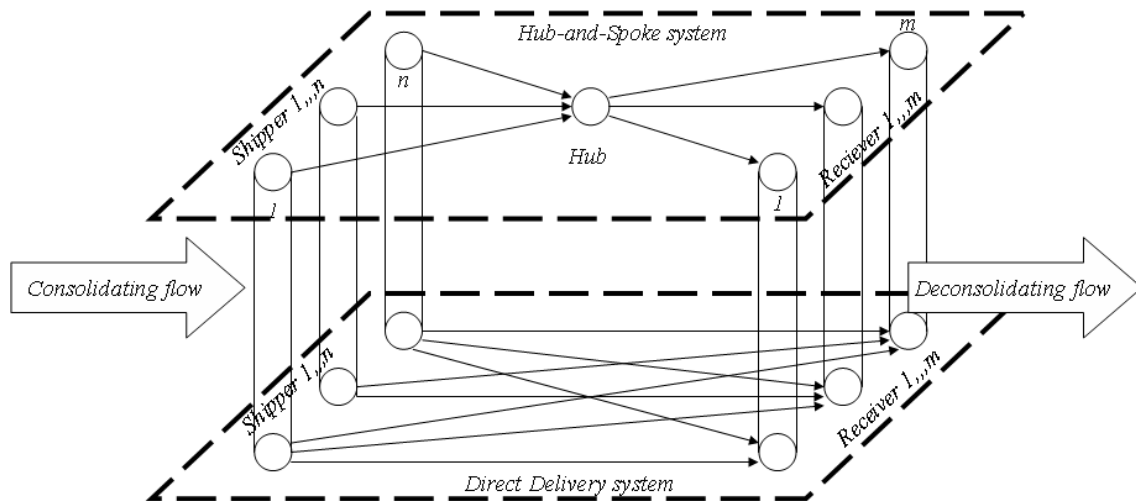


Figure 2: Representation of a foliated transportation network.
Source: Persson and Lumsden, 2006.

3.3. Related network concepts

What separates the idea of FTN from other concepts and solutions now in practice or in the focus of the transportation and logistics research community is the aim of foliating two different networks structures that are to be managed through dynamic and systematic planning and control (Persson, 2006a, Persson and Lumsden 2006).

Some of the other solutions that exist and are in operation lack some of the characteristics described above in that they are managed in an ad hoc manner. Furthermore, none seem to strive to deal with this issue systematically or at the system level. Some examples are stand-by shipments, priority classes of goods and price differentiation. Analogies can also be drawn from the field of air transportation, e.g., air passenger and/or cargo transportation.

Stand-by shipments refer to goods that are accepted and stored at the terminal and will only be delivered when overcapacity arises, i.e., the buyer accepts a flexible lead time. In practice, those types of goods will be loaded any time overcapacity in the required relation occurs; for instance, cars at Scandia Harbor³ or tires at Schenker's Bäckebol Terminal.⁴ These examples elucidate both the ad hoc nature of the solution and the lack of system overview (i.e., only the selected long distance legs are regarded on stochastic bases). Different priority goods are based on the same basic principle as the stand-by shipments, where for a lower price the customer allows the goods a longer transit time; for example, the free delivery option of books from Adlibris⁵, an online book store. This access to less time sensitive goods allows the transport network operator to distribute the low priority goods so as to make use of the overcapacity. Here the entire system can be affected. However, the approach still lacks systematic and dynamic planning and

³ Volvo Cars utilizes the over-capacity of the transatlantic ships for deliveries to America. The cars are temporarily stored adjacent to the port in question.

⁴ Michelin Tires are temporarily stored at the Bäckebol terminal and are sent across Sweden using the overcapacity of Schenker's long haul trucks.

⁵ When ordering at the online book store Adlibris, one gets to select a normal delivery (1-2 days) that will require a fee or to allow the shipment to arrive within 2-5 days for no charge. Naturally it is the service of the transportation provider that is interesting here, and not the pricing strategy of the online bookstore.

control. The third example is more a strategy for coming to terms with flow imbalances between regions and O/D pairs. The basic idea here is to generate new flows from old destinations. Another common difference between FTN and the examples is the fact that the excess capacity is undervalued in the examples, whereas in the FTN this is not meant to be the case.

Looking at the air transportation networks, similarities between FTN and passenger/freight transportation can be identified. For passengers, the basic idea of FTN is implemented in all large networks with one crucial difference. In a network of air transportation for passengers, the detailed capacity planning is not a fundamental part of the equation as passengers opt for different routes according to availability or price parameters at the time of booking/purchase. Also, the cargo in the belly hold of an airliner is accepted on grounds similar to that of a stand-by shipment with almost exactly the same effect (Acharajee, 2000).

Besides the difference in the level of planning (ad hoc vs. systematic and dynamic) and the level of attention (system wide vs. specific relations/units/origins/destinations) the FTN is distinguished from its predecessors/family members in that it aims to foliate two different network structures. This is an effort, the success of which would in principle be interesting even in other contexts besides the current one, i.e., the Swedish domestic road bound general cargo freight transportation. The concept of FTN, as presented here, has not been developed beyond its conceptual cradle and in its goal state, i.e., a fully operational model is unique and novel with a promise result that makes it well worth the research effort (Persson, 2006a, Persson, 2006b).

3.4. Optimization related to transport network

A special bounded case of the general 0/1 knapsack problem where the weight and profit are equal is called the subset sum problem (Kellerer et al., 2004, Martello and Toth, 1990). One way of looking at a Bin Packing Problem is a special case of a multiple subset sum problem where the capacity is constant (Martello and Toth, 1990). A Bin Packing Problem is a combinatorial problem of maximizing the use of a limited discreet resource and is referred to by various different names throughout the literature, e.g., cutting stock or trim loss problem, bin or strip packing problem, nesting problem, etc. (Dyckhoff, 1990).

The packing and cutting problems up to three dimensions have an easy to recognize connection to their physical applications (the general problem is not limited to three dimensions). For instance, the one dimensional cutting could be cutting as in cutting pipes or logs (Dyckhoff, 1990), the two dimensional could be cutting shapes out of sheets of paper or cloth (Lodi et al., 2002) and the three dimensional cutting could be filling a transportation unit or bin (Silvano et al., 2000). These examples are by no means exclusive or exhaustive. The mathematical problem could pertain to any planning or scheduling problem to fit the description above (Chantzara and Anagnostou, 2006, Scholl et al., 1996). As the term *Bin Packing Problem* suggests, one of the primary applications lay within transportation (Dyckhoff, 1990, Gehring et al., 1990, Silvano et al., 2000).

Another particular bounded case of the general knapsack problem is the so-called Change Making Problem where the profit is constant and set to 1 and the capacity is constraint (Kellerer et al., 2004, Martello and Toth, 1990). This issue is connected to

general cargo freight transportation in the sense of maximizing the number of shipments served by one loading unit.

4. Reference case

The reference case provides the empirical background or current state of affairs for the analysis. The studied national network, belonging to a global logistics and transportation provider, consists of a network of over 30 terminals, covering virtually every corner of Sweden. The goods shipped by the provider are divided into two groups: general cargo, which is handled through terminal(s) and is of specific interest for this study of FTN, and direct goods which are constituted of large shipments that do not pass through any terminal. Routinely, consignments totaling a combined equivalent weight less than 1000 kg are considered general cargo, regardless of their shape and packaging.⁶ The focus of this study is the general cargo section of the national network. This part of the system handles roughly 5000 tons of freight daily.

A very limited number of the trucks are actually owned and operated by the company which instead makes use of risk and profit sharing programs with “independent” haulers. The word independent is within quotation marks because the majority of haulers are in fact not independent in the true sense of the word due to the terms of the contract. Based on mutual concessions some rights and duties are shared between the company and its contracted haulers, e.g., a hauler may have the exclusive rights of a line and in return shares the risk of not getting paid for unutilized capacity.

The information system is fragmented and different sub-sections are unable of communicating with each other in real-time or automatically. For instance, the capacity and profit sharing system, the goods information system containing EDI (or physical) waybill information and the billing systems are isolated from one another. Counter intuitively, this is an advantage for this decentralized system as the experienced based low level control actually outperforms any existing control system in this highly peculiar, fragmented and low level autonomous setting. This is actually considered a positive trait of this company as a case to be selected for the study of FTN, because the system is comparable to a network of cooperating haulers with no uniform information system, which would have to be the case on the European continent where no one provider has such a dominating position in the market. This in turn could expand the scope of generalization within the boundaries of what is possible from a single case study (Yin, 2003), regarding the results.

Over 50% of the available capacity in the general cargo system is pre-booked. This means that at any given terminal on the basis of experience, implicit and explicit customer contacts, a certain amount of capacity is booked for some of the customers where they will report deviation from the norm, instead of booking, even in a case where no formal agreement exists. At any rate, pre-booked or not, more than 85% of the customers send the waybill information regarding their goods via EDI.

This information, though readily available in the system, is not utilized for planning or control. Even though the identification numbers of the physical waybills are scanned

⁶ This of course does not apply to goods requiring special attention, i.e., chemicals, provisions etc. that are bound by law to be treated separately.

2-5 times during the door-to-door service, they are not automatically connected to the corresponding digital information regarding the consignment. They can, however, be matched manually after the fact. The point of including this information is to clarify the decentralized nature of the control of these operations and the lack of central and formalized planning and control. This also furthers the analogy of comparing this single company to a network of intercompany cooperation.

A final note requiring explicit attention is the fact that the general cargo transported through this network is heterogeneous at best.

5. Analysis

On the basis of the framework and the reference case, the analysis outlines the identified research gaps following the order in which they were identified. A holistic approach is taken, which takes into consideration the added complexity of multiple unsolved issues.

5.1. Load capacity planning and control

One of the assumed prerequisites of FTN is improved or at least sustained performance compared to the current setup. This notion is the basis for the first and potentially the most critical suite of concerns.

As touched on earlier, the traits of the DS and HS setups admit that the HS setup requires more transport time than the DS structure. However, in the description above, it is apparent that what constitutes “the overhang,” i.e., the goods that are to travel through the HS layer of the network, are only available after all the DS shipments have departed. This assumes that the same control and planning principle that is used today is to be utilized even in the FTN setup. Simply put, the goods that are to travel the furthest total distance and require extra handling, i.e., extra time in transit, will depart last. This expansion of the time in transit is likely to deteriorate the performance of the system either because the goods will arrive later or orders must be placed earlier than in the current system.

One viable approach for resolving this issue is shipping, in every relation (origin destination pair), the portion of the goods that is to be the overhang first. This measure would allow the most time consuming activity the largest amount of time. This approach, however, will require an unprecedented level of capacity planning detail (Sternberg, 2008b, Christiaanse and Kumar, 2000). That detailed level is difficult to achieve for homogeneous goods in the current systems, not to mention the implications of attempting to do so regarding heterogeneous goods.

Exploring this path, many other challenges will need settling. Aside from the obvious question of the feasible level of planning and control that is to be achieved, other questions intimately associated with this issue will also need to be scrutinized. The quality and level of detail in the current customer orders needs to be established and compared to what level and quality of order data is absolutely necessary, preferable and/or feasible to expect from the transport buyers. Furthermore, the question of the impact of the need for information and accuracy, and the methods to obtain those, on the flexibility and robustness of the system, deserves attention. This also relates to

another question, the level of rigor of the governing rules of the system e.g. latest time of order entry, tolerance for accommodating last minute changes, the parameters for decentralized decision making and the ability of the system to cope with deviation from the plan need to be determined (Sternberg, 2008a).

5.2. Adding the dimension of heterogeneity

The aim of the central planning and control operations in this context is not only to prevent capacity shortages but to ensure the most efficient use of the capacity available. This notion is at the very core of FTN. The ability to effectively plan at a sufficient level of detail is one of the chief prerequisites for obtaining an efficient use of the physical resources and is thereby a system with superior performance (Power, 2005). In fact, one could argue that inept capacity planning could result in a scenario where the gains from the foliated structures would be outweighed by the poor utilization that could be a direct result of an inadequate planning effort. This respect of the issue and the impact of its outcome are amplified because of the fact that the “overhang” is to be, in advance and on a great level of detail and accuracy, identified and shipped from the terminal first.

The heterogeneity of the physical properties of the goods leads to a setting where the loading composition and loading sequence of the goods within the transportation unit will, to a degree not quantified at this moment, affect the loading capacity required. This means that even if the physical utilization rate regarding, e.g. volume, weight or length could be measured precisely (which may not even be the case) the reverse relation, i.e., planning for capacity based on aggregated weight, volume or length parameters cannot be taken for granted. It is imperative to establish what is possible to achieve in terms of planning precision for heterogeneous goods based on the existing order data. The inquiry ought not ignore what input will be required to achieve sufficient planning detail and whether other factors can be entered in, which could ultimately result in enhanced planning performance.

5.3. Adding the dimension of the Bin Packing Problem

It is not, then, only a matter of information quality/requirements on its own, but one that is complicated with a multi-dimension, multi-choice, multi-constraint Bin Packing Problem. Crassly, it means that given perfect information and absolute ability to simulate the operations necessary, the issue is still unsolved. The Bin Pack Problem, i.e., how to best fill the loading units to achieve optimum utilization, remains to be settled.

The problem is, strictly mathematically speaking, non-trivial and stands unsolved at the moment. It would be much more interesting to continue the research in this area in light of a mathematical solution to these specific problems. This also implies that the company specific traits that might add to the level of difficulty probably won't significantly alter the principle solution.

5.4. Adding the dimension of handling speed

A more, seemingly, trivial matter concerning the time aspect is one of reducing the total time in transit for the goods within the HS layer of the FTN. In order to keep that time to an absolute minimum, strategies and procedures must be devised so as to ensure

speedy handling through the additional consolidation point/s, i.e., the hub/s. The number of hubs and the extent of the detour that a hub transshipment entails can considerably affect the additional time in transit required (Kalantari and Lumsden, 2007). Therefore, in some instances it may be necessary to reduce the handling time, while on other occasions this may just improve the performance. Several approaches have been pointed out in the past, e.g., only selecting easily handled goods for the HS layer (Bjeljac and Dalibor, 2004), pre-sorting in cages (Acharajee, 2000), use of RFID (Persson, 2006a) or any combination of these and other possible operational solutions. The question of which approaches are necessary and/or feasible and to what extent, needs to be addressed.

5.5. Adding the dimension of a Change Making Problem

Mathematically, here also lies a non-trivial Change Making Problem to be addressed. This Change Making Problem, though non-trivial and unsolved in the general form, will need qualitative inputs from the refined system design for its specific solution. These inputs need to be identified and defined for a specific solution to be feasible. For illustration, the profit variable in the Change Making Problem could be as easily handled as the number of shipments put through the hub (minimize function) or a compound measure to be defined later in the lines of “handleability,” i.e., ease of terminal handling (Lumsden, 2006).

5.6. In summary of planability

This portion of the complex of problems presented above can be referred to as planability, i.e., the level and detail of planning and control that is required/feasible and its possible consequences.

In summary, it is not only a matter of data quality but it also concerns the magnifying level of the data (i.e., the level of detail and richness of data) in combination with the specific requirements of heterogeneous goods and the knapsack problem, i.e., the ability to successfully transform the data into a solid plan. The tricky part is that even success in doing so does not clear the fog and automatically lead to an uncomplicated state of affairs. There will be a point of balance between where central planning will enable better resource utilization and where it will inhibit flexibility and robustness. In order to be able to make a business decision about this trade-off, this interrelation needs to be cleared and to the extent possible, quantified. The combined effect of the planning errors, i.e., the knapsack problems and the error of the available/feasible information obtained from the consigner, like inadequate or faulty information, last minute changes etc. need to be examined.

5.7. Global Optimization

While the matters discussed in the previous sections are some of the key factors to operationalise the conceptual model of FTN, the following section is devoted to maximizing the potential of the same in practice. This area of inquiry is considered secondary and must be based on the outcome of the planability issues. Before continuing any further it must be stated that the term “optimization” is in fact incorrect, strictly speaking. As it will be apparent below, it will probably be too difficult or even

impossible to find an optimum. A sufficiently improved solution or a near optimum will for practical reasons be what is sought.

5.8. Governing rule issues

As repeated several times before, the goods that travel through the HS layer of the system will not only be in transit longer than the ones in the DS layer, but they will travel a greater distance as well. The point being made is that by sending a slightly less than 100% full truck into the DS layer, the extra distance and handling for that entire almost-full truck will be eliminated compared to it travelling through the HS layer. This then begs the question: What is the filling rate of a “full” truck? Could that be situation dependent? Or, is there a set estimated value to follow? How substantial is the effect of these decisions on the system wide performance?

Another aspect is that of hub capacity. Assuming a truck will have a fill rate slightly below what has been established, dynamically or otherwise, as a full truck, putting that additional truck through the hub would seriously congest or deteriorate the hub’s ability to handle the extra volume. Another problematic area is the impact delivering an additional truck to the hub will have on the trucks leaving the hub, i.e., the resource requirements of the hub-destination relation will be affected. For example: the system wide fill rate of a perfectly balanced hub with as much goods coming in as going out and a 100% fill rate for all leaving trucks might suffer immensely if an extra truck load were to be added to that balance. How could these aspects be considered when deciding where to send the goods systematically and automatically? How does this change the application of the solution of the aforementioned knapsack problems? These would be other factors that would require special attention when deciding the refined governing rules of a FTN. Even though these concerns are rooted partially in qualitative concerns affecting the governing rules of the FTN some equally vital mathematical issues need attention as well.

The heterogeneity of the goods contributes additional complexity to the problem. A clear notion of the solution of the knapsack problem combined with the issue of information quality is necessary for it to be possible to proceed with the optimization question. This is a question which on its own, without the complicating aspects injected, is certainly complex enough.

Clearly, these types of problems cannot at the moment be solved through analytical mathematics. Other solutions ought to be pursued, such as rule-of-thumb or a heuristics based decision support system. The two question areas posed above sum up to a system where, in theory, the distribution of goods within the different sub structures of the system needs to be reconfigured after every order entry. An alternative to the abovementioned approaches could be the exploitation of ideas from adaptive logistics (Dorer and Calisti, 2005, Nilsson, 2005) and agent based modeling and simulation (Neagu et al., 2006). These speculations will, however, not be further developed in this document since they fall outside of the scope of this paper.

The aspect that is closely connected to this area and its inquiry and should perhaps precede the optimization research is the quantified theoretical and feasible practical potential of a functioning FTN. The rules governing such an unpolished still “under construction” system could in a sense be arbitrary, as long as they adhere to the basic conceptual idea.

6. Results

The results of the analysis of research gaps related to FTN are illustrated in figure 3.

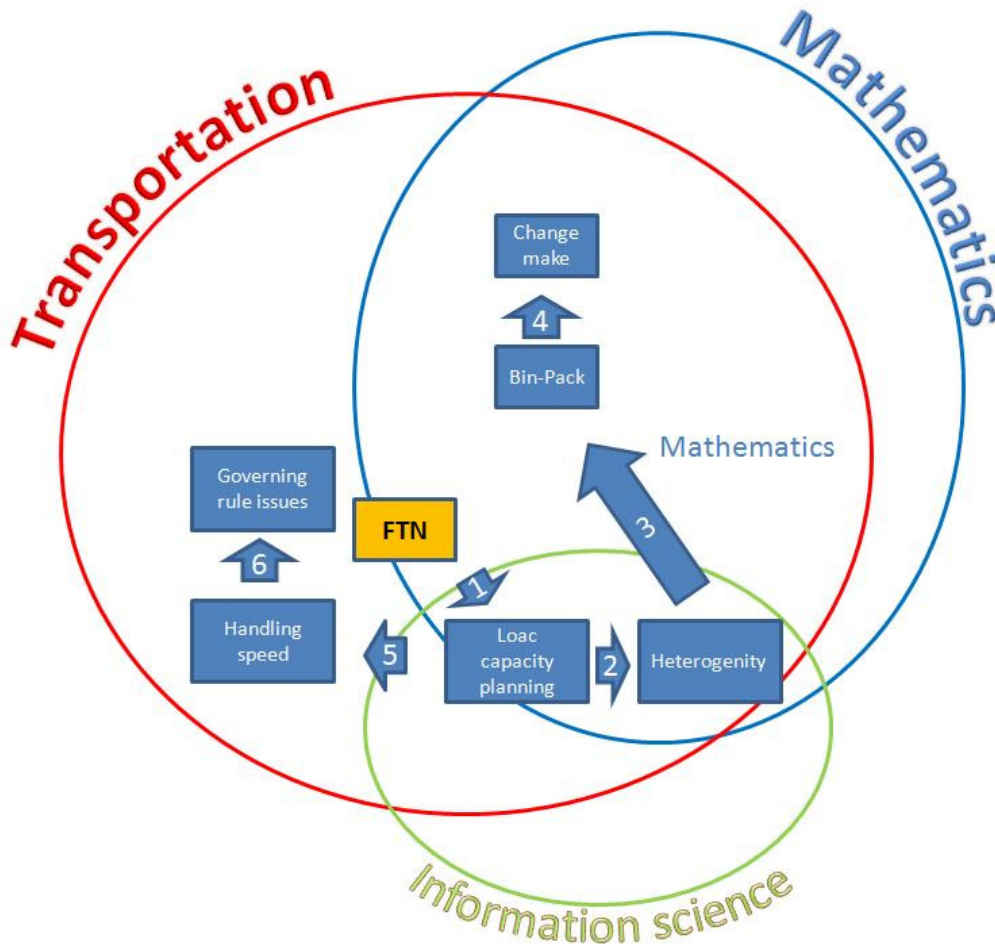


Figure 3: Road map of FTN research. Circles depict areas of science, boxes depict researchable gaps and the arrows depict the suggested research path.

Both literature and interviews identified the *load capacity planning and control* (transport planning) as the initial research point of the concept. Transport planning lies in the intersection of transportation and information science. Adding *heterogeneity* to the transport planning creates new dimensions to all of the planning related areas, both to mathematical optimization and information requirements to operationalise FTN. These gaps find a relevant formulation and possible solution in the literature of combinatorial mathematics in general and specifically as general problems within the *Bin Packing Problem* and *Change Making Problem*. The transportation planning and control required are concluded to be dependent on adequate solutions to correctly formulated specific cases of these general mathematic problems.

Through the workshops and interviews, and also based on previous research, the *handling speed* was identified as another important issue to deal with in the design of an operational model. Finally, several other issues related to the control of the system were

identified, labeled as *Governing rule issues*. The current state and level of abstraction of this conceptual model leaves plenty of unresolved questions regarding these aspects, which are closer to an operational design of the model.

Table 1: Research gaps and road map to future research on FTN.

| <i>Research Gap</i> | <i>Research area</i> | <i>Implications</i> | <i>Relation to FTN</i> |
|------------------------------------|--|---|---|
| Load capacity planning and control | Transport planning Information systems | Derived mainly from study on management in the empirical setup and transport literature | The core of the operational model |
| Heterogeneity | Transport planning Information systems | Mainly derived from the empirical setup | Needs to be addressed in order to make the model operational in a large-scale setup |
| Bin Packing Problem | Transportation Mathematics | Theoretically derived | Planning and control algorithms |
| Change Making Problem | Transportation Mathematics | Theoretically derived | Optimization algorithm |
| Handling speed | Transportation | Mainly derived from the empirical setup | Needs to be addressed in order to make the model feasible |
| Governing rule issues | Transportation | Derived both empirically and theoretically | Needs to be addressed in order to make the model feasible |

7. Conclusions

It is concluded that the research effort is to be directed toward the four main areas of transport management, transport planning, planability and optimization. The former issue involves solving the question of the combined effect of the knapsack problems and information quality for the planning and control performance. The latter pertains to the governing rules or design principles that would afford the best system wide performance.

Table 1 summarized the research needs identified in the paper. The combination of the two aspects presented creates a problem. A proper solution will offer a scientific contribution to both theory and practice.

Given the detailed level of feasible planning and its coherence with the idea of FTN, a network optimizing set of rules regarding the distribution of goods between different trucks and network layers ought to be developed. The performance of the final network design and its governing rule should, of course, be evaluated.

The performance resulting system design and governance is to be evaluated with respect to the potential for improvement compared to the state of the art systems of the

present day and the cost (not necessarily a money measure) of achieving an operational FTN.

Acknowledgements

The authors of this paper would like to thank Vinnova for their financial support, Schenker DB Sweden and Volvo Logistics for their cooperation in the collection of empirical data, and Professor Kenth Lumsden for his ideas and support for this paper. Many thanks to all the colleagues from near and far who participated in the seminars and workshops.

References

- Acharajee, P. (2000) "Capacity Utilization of the Belly-Hold in Line-Based Air Traffic", *Department of Transportation and Logistics*, Göteborg, Chalmers University of Technology.
- Arnäs, P. O. (2007) "Heterogeneous Goods in Transportation Systems - A study on the uses of an object-oriented approach", *Department of Technology Management and Economics*, Göteborg, Chalmers University of Technology.
- Bjeljac, R. and Dalibor, L. (2004) "Överlagrade hubsystem, vad krävs för en implementering hos Schenker?", *The Devision of Transport and Logistics*, Göteborg, Chalmers University of Technology.
- Brehmer, P.-O. (1999) "Towards a Model of Lean Freight Transport Operation", *Logistics and Transport Systems*, Linköping, Linköpings Institute of Technology.
- Caputo, A. C., Fratocchi, L. and Pelagagge, P. M. (2005) "A Framework for Analysing Longrange Direct Shipping Logistics", *Industrial Management & Data Systems*, pp. 876-899.
- Chantzara, M. and Anagnostou, M. (2006) "MVR heuristic for Solving the Multi-Choice Multi-Constraint Knapsack Problem", In: Alexandrov, V. N. (Ed.) *International Conference on Computational Science*, University of Reading, UK, Springer-Verlag.
- Christiaanse, E. and Kumar, K. (2000) "ICT-enabled coordination of dynamic supply webs", *International Journal of Physical Distribution & Logistics Management*, 30, pp. 268-285.
- Closs, D. J., Swink, M. and Nair, A. (2005) "The role of information connectivity in making flexible logistics programs successful", *International Journal of Physical Distribution & Logistics Management*, 35, pp. 258-277.
- Crainic, T. G. (2002) "A Survey of Optimisation Models for Long-Haul Freight Transportation", In: Hall, R. W. (Ed.) *Handbook of Transportation Science*, Kluwer.
- Crainic, T. G., Ricciardi, N. and Storchi, G. (2004) "Advanced Freight Transportation Systems for Congested Urban Areas", *Transportation Research Part C*, 12, pp. 119-137.
- Dorer, K. and Calisti, M. (2005) "An Adaptive Solution to Dynamic Transport Optimization", *Fourth International Joint Conference on Autonomous Agents & Multi Agent Systems*, Utrecht University, The Netherlands.
- Dubois, A. and Gadde, L.-E. (2002) "Systematic Combining: an abductive approach to case research", *Journal of Business Research*, 55, pp. 553-560.
- Dyckhoff, H. (1990) "A Typology of Cutting and Packing Problems", *European Journal of Operational Research*, 44, pp. 145-159.
- European Commission, D. E. A. T. (2003) "Energy and Transport: main figures", *Energy and Transport Outlook to 2030 EU-15*.
- Flick, U. (2006) *An Introduction to Qualitative Research*, London, Sage Publications.
- Gehring, H., Menschner, K. and Meyer, M. (1990) "A Computer-Based Heuristic for Packing Pooled Shipment Containers", *European Journal of Operational Research*, 44, pp. 277-288.
- Hultkrantz, O. (1999) Networks in Road-Based Traffic, *Department of Transportation and Logistics*, Göteborg, Chalmers University of Technology.
- Kalantari, J. and Lumsden, K. R. (2007) "Stepwise Replacement of a Direct Shipment Network with a Hub and Spoke System", In: Halldórsson, Á. and Stefansson, G. (Eds.) *The 19th Annual Nofoma Conference*, Reykjavik, Iceland.
- Kellerer, H., Pferschy, U. and Pisinger, D. (2004) *Knapsack Problems*, Berlin, Springer.
- Kreutzberger, E., Macharis, C., Vereecken, L. and Woxenius, J. (2003) "Is Intermodal Freight Transport More Environmentally Friendly than All-Road Freight Transport? - A Review", *NECTAR Conference No 7*, Umeå, Sweden.
- Landers, T. L., Cole, M. H., Walker, B. and Kirk, R. W. (2000) "The virtual warehousing concept", *Transportation research, Part E*, pp. 115-125.
- Lodi, A., Silvano, M. and Monaci, M. (2002) "Two-Dimensional Packing Problems: A Survey", *European Journal of Operational Research*, 141, pp. 241-252.
- Lumsden, K. (2006) *Logistikens Grunder*, Lund, Studentlitteratur.
- Lumsden, K., Dallari, F. and Ruggeri, R. (1999) "Improving the Efficiency of the Hub and Spoke System for the SKF European Distribution Network", *International Journal of Physical Distribution & Logistics Management*, 29, pp. 50-64.
- Manheim, M. L. (1979) *Fundamentals of Transportation Systems Analysis*, Cambridge, Massachusetts, MIT Press.
- Martello, S. and Toth, P. (1990) *Knapsack Problems - Algorithms and Computer Implementation*, Chichester, England, John Wiley & Sons.

- McKinnon, A. C. (1994) *Logistics and the Environment*, Edinburgh, United Kingdom, Heriot-Watt University Business School.
- McKinnon, A. C. (1995) *Opportunities for Rationalising Road Freight Transport*, London, Church House.
- McKinnon, A. C. and Ge, Y. (2006) "The potential for reducing empty running by trucks: a retrospective analysis", *International Journal of Physical Distribution & Logistics Management*, 36, pp. 391-410.
- Nanos-Pino, J., Carrera-Gómez, G., Coto-Millán, P., Inglada, V. and Pesquera González, M. (2005) "Technical Efficiency of Road Haulage Firms", *Transportation Research Record: Journal of the Transportation Research Board*, 1906, p. 26-32.
- Neagu, N., Dorer, K., Greenwood, D. and Calisti, M. (2006) "LS/ATN: Reporting on a Successful Agent-Based Solution for Transport Logistics Optimization", *IEEE 2006 Workshop on Distributed Intelligent Systems (WDIS)*, Prague, Czech Republic.
- Nilsson, F. (2005) "Adaptive Logistics - using complexity theory to facilitate increased effectiveness in logistics", *Department of Design Sciences*, Lund, Lund University.
- Persson, P.-O. (2006a) "Identification Technologies in Transportation - In the Context of Foliated Transportation Networks", *29th Australian Transport Research Forum*, Gold coast, Australia.
- Persson, P.-O. (2006b) "Traceability of Goods in a Transportation Network and the Potential Impact on Logistics And Transportation Services", *4th International Logistics and Supply Chain Congress*, Izmir, Turkey.
- Persson, P.-O. and Lumsden, K. R. (2006) "Foliated Transportation Networks", *Logistics Research Network*, Newcastle, United Kingdom.
- Persson, P.-O. and Waidringer, J. (2006) "Foliated Transportation Networks", In: Jahre, M. (Ed.) *18th Annual NOFOMA Conference*, Oslo, Norway.
- Power, D. (2005) "Supply chain management integration and implementation: a literature review", *Supply chain management: an International journal*, 10, 252-263.
- Rodrigue, J.-P. (1999) "Globalization and Synchronization of Transport Terminals", *Journal of Transport Geography*, 7, 255-261.
- Ross, D. F. (1996) *Distribution Planning and Control*, Boston, MA, Kluwer Academic Publishers.
- Scholl, A., Klein, R. and Jürgens, C. (1996) "BISON: A Fast Hybrid Procedure for Exactly Solving the One-Dimensional Bin Packing Problem", *Computer Ops Res.*, 24, pp. 627-645.
- Silvano, M., Pisinger, D. and Vigo, D. (2000) "The Three-Dimensional Bin Packing Problem", *Operations Research*, 48, pp. 256-267.
- Sommar, R. and Woxenius, J. (2007) "Time Perspectives on Intermodal Transport of Consolidated Cargo", *European Journal of Transportation and Infrastructure Research*, 7, pp. 163-182.
- Stefansson, G. (2006) "Collaborative Logistics Management and the Role of Third-Party Service Providers", *International Journal of Physical Distribution & Logistics*, 36, pp. 76-92.
- Sternberg, H. (2008a) "Freight Transportation Operations and Information Sharing", *Division of Transportation and Logistics*, Göteborg, Chalmers University of Technology.
- Sternberg, H. (2008b) "Transportation Visibility and Information Sharing - a case study of actors' requirements", *World Review on Intermodal Transportation*, Forthcoming.
- Travisano, J. J. (1996) "Lessons Learned: The Object-Oriented Design of StarView", In: Jacoby, G. H. & Barnes, J. (Eds.) *Astronomical Data Analysis Software and Systems V, A.S.P. Conference Series*.
- Waidringer, J. (2001) "Complexity in transportation and logistics systems : an integrated approach to modelling and analysis", *Department of Transportation and Logistics*, Göteborg, Chalmers University of Technology.
- Williams, J. D. (1996) "Managing iteration in OO projects", *Computer*, 29, pp. 39-43.
- Yin, R. K. (2003) *Case Study Research - Design and Methods*, Thousand Oakes, Ca, Sage Publications.