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Foliated Transport Networks in Intermodal Freight Transport

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Abstract: Foliated transport networks represent a concept that aims to improve the efficiency of the transport system by combining direct connections and hub and spoke design. In addition to combining these designs, a foliated transport network requires a high level of dynamic planning and control, as well as optimisation of goods and resources between the different network layers. It highlights the advantages of individual transport network designs and minimizes their weaknesses, ultimately leading to better performance of the foliated system than the individual options. The purpose of this paper is to describe the basic models of the freight transport network and the benefits of connecting these models. This survey paper aims to provide an overview of previous research in the field of foliated transport networks and to provide future research guidelines in this field that include the application of this model in intermodal transport.

Keywords: foliated transport networks; mixed networks; intermodal transportation; digital transformation; road transport; rail transport; hub and spoke; direct connection; transportation; environmental sustainability

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1. Introduction

Transport can be defined as demand that creates temporal and spatial utility by moving goods and increasing their value when they are needed [1]. In organising and managing transport, three levels of decision-making can be analysed: strategic, tactical and operational [2]. At the strategic level, a decision is made on the spatial location of the terminal. The choice of transport mode is made at the tactical level. At the operational level, the optimal routes are selected [3]. Tactical planning consists of a series of interrelated decisions to ensure the optimal allocation and use of resources. Tactical planning is particularly important for consolidated cargo transport. The design of the transport network is increasingly used to determine the key tactical issues in freight transport [4]. The essential elements of the transport network are nodes and links. A node is a location or transhipment point where loading, unloading, sorting, storage and change of mode of transport take place. Links are transport activities that connect nodes to form a transport network. A transport network is formed by connecting all source and destination nodes with links to a sufficient number of transhipment nodes [5,6]. There are different types of links between nodes and the choice of the link depends on several criteria. Some of the criteria for choosing the link between nodes are the quantity and type of goods, the location of the nodes and the distance between them, and various parameters of the available transport modes such as speed, price, condition of transport infrastructure and others.

This paper considers the two most used connections between nodes within the transport network, the direct connection and the hub and spoke. The direct connection, i.e., direct transport, is used for large volume consignments and filled vehicle capacities. Such consignments are sent directly from Node A to Node B, as additional freight handling incurs unnecessary costs. Hub and spoke, on the other hand, is suitable for small consignments and consolidated shipments, as all freight from the source nodes is first sent to the central terminal, known as the hub, where it is consolidated and then distributed to the destination nodes. The hub's main function is efficient handling and optimal utilisation of transport capacity. According to [7], the concept of hybrid transport systems, called the Foliated Transportation Network (FTN), was first mentioned by Persson and Lumsden and Persson and Waidringer in 2006. Foliated transport networks represent a concept that aims to improve the efficiency of the transport system. Freight is transported directly when the vehicle is filled to the point of minimum cost efficiency at full capacity. Otherwise, the goods are transported via the hub [7]. This concept combines the advantages of a hub and spoke system with the flexibility of direct transport using real-time information combined with dynamic planning, control and optimisation [7].

This paper presents an overview of research in the field of foliated transport networks and the direct and hub and spoke networks that make up this concept. This paper is divided into four chapters. The second chapter, after the introductory part, describes the transport networks in more detail and gives a brief overview of previous research on direct and hub and spoke networks. The third chapter introduces the concept and an overview of research on foliated transport networks, a mixed model of the application of direct and hub and spoke connections. The fourth chapter is a conclusion with an analysis of previous research and guidelines for future research in this area.

2. Organisation of Freight Transport in Transport Networks

For transport to be intermodal, it must meet certain conditions, namely the presence of intermodal units, in the form of swap bodies, semi-trailers or containers in which the freight is transported from the origin to the final destination, changing at least two transport modes during the realisation of a transport chain [5,8–12]. Intermodal transport uses all the advantages of the transport modes, while the disadvantages such as low flexibility, poor availability and the impossibility of door-to-door delivery are supplemented by road transport to a minimal extent. Intermodal transport is constantly trying to compete with road transport and one way to do it is to optimise transport processes. The possibility of shifting road demand to intermodal rail-road transport mainly depends on the length of the whole route [13]. Contrasted with the unimodal road transport, multimodal transport (using more than one mode of transport) is potentially more feasible as it saves costs and has less impact on the environment [14].

The intermodal transport nodes as intermodal terminals represent the loading and unloading points as well as the transhipment points between the different modes of transport, while the connections between the nodes represent routes that differ in distance and mode of transport. Intermodal terminals are one of the most important components of the combined transport infrastructure and provide an important link between individual modes of transport [15]. The automated container terminal (ACT), which is considered as an inevitable trend for the future modernisation of ports, serves as a type of connecting node for the transport of goods between different regions and countries. Operations at ACT can be improved, better managed, faster and more efficient through the use of artificial intelligence (AI) [16]. The choice of connections in the transport network is influenced by geographical and infrastructural conditions, the demand for transport services and the quality of transport modes [5].

Author Woxenius proposes six different principles for the design of transport systems. Nodes (terminals) can be connected by direct links, corridors, hub and spoke, connected hubs, fixed (static) routes and flexible (dynamic) routes. Figure 1 shows three of six possible designs; (a) Direct link, (b) Hub and Spoke, and (c) Connected hubs. The blue circles represent the origin and destination nodes and the green pentagons represent hub terminals. Direct connection is equivalent to a point-to-point network, where a direct link connects each origin point to a destination point. In the hub and spoke system, a single node is defined as the central terminal through which all transport must pass, even if the distance between the nodes is shorter when goods are transported directly. As shown in Figure 1, connected hubs are a mixed transport network organisation in which local cargo flows from satellite terminals are collected in hubs and hubs are connected at the regional level by direct links. Connected hubs are often used in container transport, where feeder vessels, barges, shuttle trains or trucks supply the hubs with cargo and containers. Direct links between hubs are often made by block trains and shuttle trains [17]. The connected hubs model is a type of hub and spoke system where satellite links connect nodes to hub terminals and inter-hub links connect pairs of hubs. Inter-hub links can be referred to as primary routes and satellite links as secondary routes [18,19].

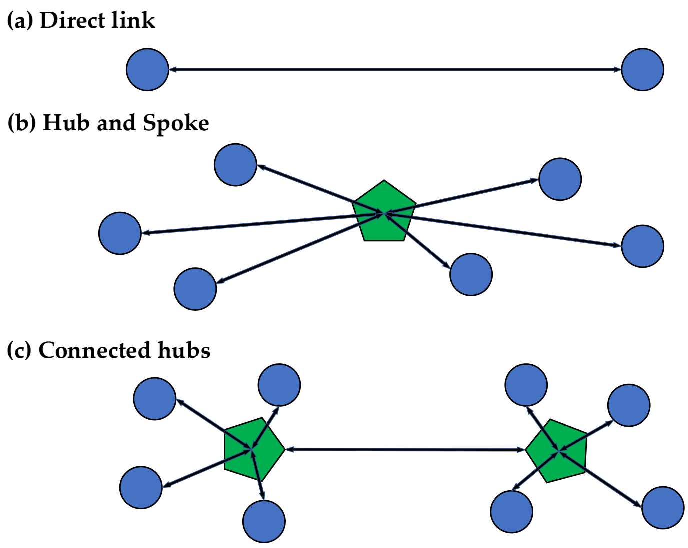

Figure 1. Different designs of a transport network. Source: Made by the authors.

Direct links and hub and spoke systems will be described as the two predominant network structures in the transport system. Depending on their characteristics, they find a wide range of applications in freight transport. Their combination in the model of a foliated transport network can significantly improve the efficiency of the transport system.

2.1. Direct Link Design

The most direct way to connect a certain number of points at different geographical locations is a direct link. This system is equivalent to a point-to-point network, where a direct link connects each origin point to a destination point. As the number of origin and destination nodes increases, the distribution network and the number of connections increase exponentially [20]. A direct link is a direct connection between an origin and a destination without involving other nodes [17]. The direct link has the highest degree of flexibility. It is most efficient when the flow of goods is large enough, i.e., when the transport capacities are utilised. When the utilisation is low, the direct connection between two terminals is no longer profitable. In this case, it is better to consolidate the cargo in one of the transhipment nodes. A direct link assumes that all cargo loaded at the origin terminal has the same destination. Such a concept requires a constant high volume of cargo on certain routes [21]. A direct link is used when the delivery time is short, when the goods should not be mixed with other goods and when the shipments are large enough to fill the loading space [22].

In intermodal transport, direct trains over long distances are economical only when the frequency and volume of goods are high. If smaller shipments are observed, it is better to use a different transport design model for longer distances, while direct links are recommended for shorter distances. Lower volume means a volume of freight that is below what is economically feasible for direct trains. This volume varies depending on the region where the transport takes place because, as it depends on the transport prices, subsidies, restrictions on road transport and other factors. In Europe, a short distance is generally considered to be shorter than 500 km, while in the US, distances less than 500 miles are meant as short [5,17,23,24].

2.2. Hub and Spoke Design

In the hub and spoke system, a single node is defined as the central terminal through which all transport must pass, even if the distance between the nodes is shorter when goods are transported directly. This transport design method was developed in areas with a dominant centre and satellite terminals dependent on it [17,25]. The key factors in designing a thriving hub and spoke network are determining the optimal number of hub terminals and their appropriate location and allocating satellite terminals to hub terminals [26]. Hub and spoke design leads to savings in operating costs and improves the service offering and market position [27]. Hub and spoke networks are widely used in many aspects of life, such as telecommunications, mail distribution, emergency services, computer networks, transportation systems, etc. [28]. The implementation of the hub and spoke design in intermodal transport has been proposed as one of the possible solutions to increase the share of intermodal transport in total freight transport [21]. When the volume of goods fluctuates and a small amount of freight needs to be transported, it is advisable to consolidate the freight in the central terminal (hub). In intermodal freight transport, the central terminals are usually intermodal terminals where the change of transport mode takes place simultaneously. The main advantage of a hub and spoke system is that it connects many nodes with a high frequency, although the traffic flows between each pair of nodes are minimal. In a pure hub and spoke system, only two links are required to connect all origin and destination nodes [17].

The locating of a hub terminal is part of the strategic planning process. The most important parameters for modelling hub and spoke networks and locating hubs are demand, transport costs, time, the flow of goods and the cost of building the hub [29–33]. Author O'Kelly [34] focuses on geographical issues involved in modelling the location of air transport hub terminals. The authors Limbourg and Jourquin [35] studied the hub and spoke network in road-rail transport, i.e., the determination of optimal locations for hub terminals in Europe. In their work, calculations for the optimal location of the hub in a pure hub and spoke network (p-hub median) and for the optimal location of connected hubs (p-hub centre) are performed on the example of combined transport. A similar problem was solved by Jeong et al. using the hub and spoke network in rail freight transport in Europe as an example. The authors apply linear programming and various heuristic algorithms to the actual freight volumes in 48 terminals across Europe to determine which terminals can be considered as hub centres and which terminals they serve. Compared to the algorithms used by authors Cranic et al. in 1984. this model yields approximately the same results. For example, the authors find that the most important terminals in the European rail network are located in France and Germany. Compared to the United States and Canada, it is much easier to implement the hub and spoke concept in the European railway system because the rail network and infrastructure are better developed [36].

The authors Lin et al. [37] defined the classification of hub and spoke networks. Lin and Chen [18] showed that classes in air transport in an example of Asia. The authors proposed a generalised hub and spoke network that integrates the three most common classes of the hub and spoke networks used for specific transport needs: (1) pure hub and spoke network; (2) hub and spoke network with stopovers and feeders; (3) hub and spoke network with stopovers, feeders and centre directs. A pure hub and spoke network consists of a central terminal and satellite terminals, and every transport in the network must pass through a hub terminal [18]. In addition to the connections between nodes and hubs, the second class connects the hub with a series of feeder lines that supply the hubs with freight. Stopovers are used to increase the load factor of the vehicles by making intermediate stops at distribution centres on the existing route. These intermediate stops can keep vehicle utilisation above the minimum threshold for profitability [38,39]. The third class differs from the second class in its operational flexibility. While picking up freight at one of the centres, goods for that node can be unloaded at the same time without transferring goods at the hub. When a vehicle on secondary routes stops at a node to pick up the additional cargo, the carrier can simultaneously unload the delivered cargo, freeing up the vehicle's capacity [18].

Hub and spoke networks can also be subdivided according to the allocation criteria, so there are single allocation models and multiple allocation models of hub and spoke networks. According to [40], Campbell et al. (2002), Skorin-Kapov et al. (1997), and Ernst and Krishnamoorthy (1996) are some of the authors who address the single allocation problem, while Campbell (1992, 1996, 2002), Ernst and Krishnamoorthy (1998) and Boland et al., (2004), address multiple allocation problem in their works. In the single allocation model, all transport occurs through a single hub. In contrast, in the multiple allocation model, goods can be sent from nodes via different hubs, depending on which is more convenient given the final destination. Teodorović et al. [26] solved the single allocation problem of the hub and spoke network with a model based on the Bee Colony Optimisation (BCO) metaheuristics. Comparing the results obtained with the BCO method with the optimal results obtained with the CPLEX method, it can be seen that the results are the same and that the CPU (problem-solving time) is much shorter with the BCO method, which makes this method competitive [26].

2.3. Comparison of Hub and Spoke and Direct Design

By bundling goods in hub terminals, hub and spoke networks offer four main advantages over direct networks. The first relates to a higher utilisation coefficient of vehicle capacity, which reduces costs. Second, there are economies of scope in the use of shared transhipment facilities. The last two benefits are reflected in economies of scale. Economies of scale at connections increase service quality by providing a high frequency of service and better service to terminals with lower cargo volumes. The last are economies of scale at hubs, which allow for the potential development of an efficient distribution system as hubs handle larger volumes of traffic [21,41,42]. Observing hub and spoke systems in air transport, whether environmental impact or environmental external costs, the hub-and-spoke network is less polluting than the city-to-city (direct) network [43].

The advantages of direct lines are obvious when freight flows are sufficient for a satisfactory departure frequency, but combining them with other transport models generates lower logistics costs and increases service quality. The decision of whether to ship goods directly or consolidated them at the hub terminal depends on several parameters [17,44]:

- Shipment size: the closer the shipment is to full capacity, the more direct the transport will be,
- Transport distance: the shorter the distance, the more direct the shipment,
- Delivery time: higher requirements, more direct shipments,
- Product characteristics: specific products, more direct shipments,
- Availability of other freight along the route: less availability, more direct shipments.

With direct deliveries, smaller suppliers should wait to deliver until a sufficient quantity of goods has been ordered to maintain the transport economy. With a hub system, suppliers can offer a higher frequency of delivery by pooling their demands or orders with other suppliers. If each supplier's customers are located very close to the supplier and the delivery volume is large enough to justify delivery at the full capacity of the vehicle, the direct delivery system is better. Otherwise, it is more convenient to use a hub and spoke system [22].

The disadvantages of the hub and spoke system compared to direct delivery are primarily congestion or manoeuvring in the hub terminal, which requires additional time and incurs additional costs, reducing the reliability of the door-to-door transport chain. The diversion via the terminal also causes additional costs and time compared to a direct connection [41].

In his work, the author Hall [45] develops the process of deciding whether a shipment is sent directly or via a hub terminal. All values below the break-even point represent optimal flows for direct transport, while everything above this point generates lower costs if transported via the hub. The calculation of the break-even point includes the freight flows between origin and destination, the transport costs via the hub and direct, the travel time direct and via the hub, and the total freight flows from origin to hub (as the hub can consolidate freight for multiple destinations). The cost of the direct link became minimal when vehicle capacity was utilised. Using container shipping by sea as an example, authors Hsu and Hsieh developed a mathematical model that decides whether a shipment should be sent via a hub or directly. This model can reduce transport costs and storage costs. The results of the research showed that when container flows increase, there is a tendency to use direct connections [46].

In [20], the authors Lumsden et al. describe the introduction of a hub and spoke system to replace the direct connections of Europe's road transport network. The new distribution network has half as many connections as the previous model. The total length of links was reduced to one third (35,000 km) of the total length of links in the direct link model (117,000 km). The authors conclude that opting for a hub and spoke system is positive as it increases vehicle utilisation and travel frequency while reducing transport costs.

3. Foliated Transport Networks (FTN)

With the development of information technologies and their application in transport and logistics, new solutions and combinations of classical transport systems become feasible. By creating new ways to organise the physical flow of goods, the transport network can be better designed and managed [7]. Combining a hub and spoke system with a direct shipment network structure creates a hybrid. This chapter provides an overview of the research describing the combination of direct and hub and spoke systems. Different authors have named this concept with different terms, such as mixed delivery systems, hybrid shipment control and foliated transport networks. The Swedish term "överlagrad" was first used by the authors Bjeljac and Lakobrija in 2004, while the authors Persson and Waidringer defined the English translation as "foliated" [47]. A literature search in various databases (Science Direct, Scopus, Emerald, ProQuest, DiVa) for the key terms foliated transportation and foliated transport network found nine papers dealing with the concept of the foliated transport network. Other papers that use the term foliated are not from the transport sector. All nine papers have at least one author from Sweden. Some other works combining direct and hub-and-spoke systems are mentioned in this chapter, but they do not use the term foliated, but some others like mixed and hybrid systems.

Foliated transport networks represent a concept that aims to improve the efficiency of the transport system, i.e., the use of resources in terms of vehicle capacity, without degrading other quality or performance parameters. The aim is to improve the efficiency of the transport system by combining the two prevailing network structures, direct link and hub and spoke [48]. Freight is shipped directly when the vehicle is filled to the point of minimum cost efficiency for full occupancy. If the quantity of goods does not exceed the point of minimum cost efficiency the goods are transported via the hub and spoke system [7]. The combination of these structures, together with the dynamic planning, control and optimisation of the distribution of goods and resources between the two structures, simultaneously enhances the strengths of each model and minimises its weaknesses, resulting in better system performance than individual options. In other words, physical resource utilisation increases without degrading other key performance indicators, such as total traffic work (truck capacity multiplied by the distance travelled), number of resources in the system, execution time, flexibility, etc. [48]. The efficiency improvements that result from the introduction of the foliated transport network are not due to decreased customer service. The quality of service is the same or better in the hybrid model but requires the ability to plan and control the trajectories of individual shipments through the network [49].

Figure 2 shows a foliated transport network model where complete freight units are shipped directly on the lower layer. All freight on a route that is not sufficient for a cost-efficient direct link is consolidated in the hub terminal shown in the upper layer. This results in a significant reduction in the number of connections on which underutilised units can be sent. At the same time, the considerable advantages of consolidating in hub and spoke terminals are utilised. The goal of foliated transport network is to take advantage of the positive effects of classic transport models, direct links and hub and spoke. It is a trade-off between some of the losses that occur and the overall benefits of combining the two models. Losses can be higher transport work (volume of goods shipped multiplied by distance) and longer travel times because hub and spoke systems are added to direct transport. On the other hand, however, there is lower traffic work due to fewer vehicles, higher resource utilisation, a variety of services, and overall environmental efficiency, which can be considered as network benefits [5].

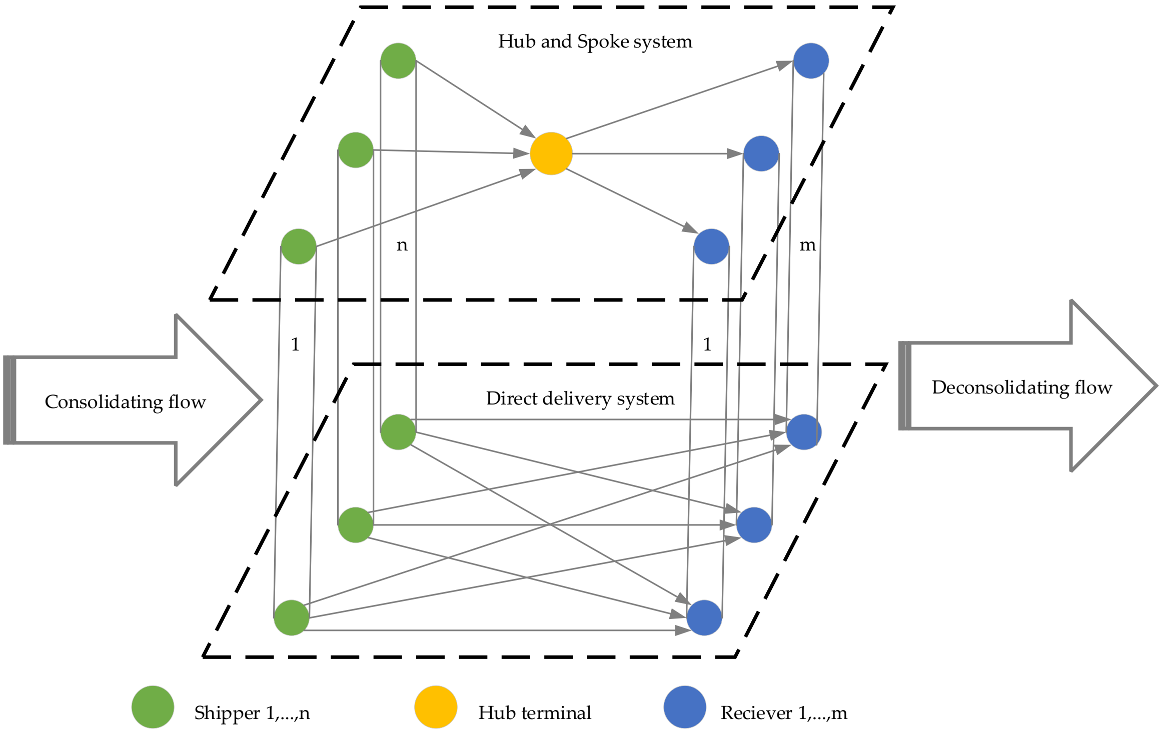

Figure 2. Foliated transport network model. Source: Made by the authors according to [7].

The author of the paper [47], according to Bjeljac and Lakobrija, proposes a model in which the quantities of goods sent to the hub terminal are defined and distributed after the direct shipments have been dispatched. In the same paper, when designing the model according to Persson and Lumsden, the author proposes a second model in which the number of goods sent to the hub terminal is pre-determined and dispatched first to improve system efficiency in terms of mean time between network nodes. Since the transit time through the hub and spoke network is inherently longer compared to a direct link, it would be useful to allow the most extended time window by sending this cargo first. This approach requires a very high degree of accuracy in operational planning and control [47].

In their paper, the authors Kalantari and Sternberg present the perspective of future research for foliated transport networks (FTN). The authors define this model as a conceptual model of combining direct links and hub and spoke, which aims to achieve higher utilisation of vehicle freight space without increasing traffic at the same time. What distinguishes this model from other solutions is the fusion of different network structures through dynamic and systematic planning and control. The authors conducted the study at over 30 terminals in Sweden. The information system is divided, and different subgroups cannot communicate or exchange information in real-time. Adding heterogeneity to transport planning creates new dimensions for all areas of planning, both for mathematical optimisation and the information needs when using FTN [48].

In his work, Kalantari [50] quantifies the potential of the FTN concept using a discrete simulation model. The loading limit was lowered from 100% to 75% for direct shipments.

The results obtained show that with the FTN concept, the average truck loading rates at the system level increased by almost 15%, the minimum number of trucks required decreased by over 10%, the total transport work increased by over 5% and did not change compared to the traffic work in the direct transport system.

The case study in the paper [51] shows the distribution of consumer goods by a combination of road vehicles and barges in inland waterways. The paper presents a collaborative hub network in which inland waterway transport (IWT) is used for transport between hubs to achieve economies of scale. In parallel, direct connections are used to maintain the economy and flexibility. In this way, logistics costs are reduced and the level of logistics services is maintained. In intermodal hub networks, cooperation between shippers and forwarders is necessary to ensure a synchronised network organisation [51].

In their paper, Liu et al. [22] presented a model for mixed truck deliveries combining direct and hub and spoke models with milk run options. Without milk run deliveries, the vehicles transport directly or via hub for only one destination, resulting in high costs with insufficiently filled vehicle capacities. Introducing milk run deliveries lowers transport costs as each vehicle goes to multiple locations. When grouping shipments, the quantity of goods does not exceed the maximum capacity of the vehicle. When the milk run model is incorporated into the transport network, a vehicle routing system must be developed, and in this paper it is a heuristic algorithm. Depending on the amount of freight, it is decided whether the goods are consolidated in the hub terminal or sent directly to the destination. The authors estimate the potential saving of 10% of the total distance travelled using this system compared to pure systems [22].

The study by Zapfel and Wasner examined the operational decisions of hub and spoke systems and developed a mathematical decision model applicable to the specific case of an Austrian parcel service provider. The model decided whether to use a pure hub and spoke system or an extended or foliated transport network with direct connections. Ten nodes and one hub terminal were considered in the study. The authors describe that the savings achieved by applying the model and introducing a foliated transport network averaged 10% of the total transport costs. Total costs can be even lower if freight volumes are consolidated through cooperatively overlaps of deliveries and pick-ups at hubs, which reduces empty miles (the distance a vehicle travels without the goods). This model was also tested on the Germany hub and spoke system used for LTL (Less than Truck Load) shipments, and it was concluded that it can be applied to freight transport in general [52].

Authors Hakimian and Zandi [53] present the FTN model, generate optimal solutions with the Arena 10 simulation programme, and propose additional services and activities in the hub terminal that would promote the use of the hub network. It can be concluded that there are different transport options, but users try to transport direct shipments as often as possible. As long as there are no incentives for consolidating shipments at the hub terminal, the lines via the hubs will be underutilised, which is sometimes cost-efficient for the users. However, the environmental aspect should also be taken into account, as insufficiently filled vehicles on the direct lines have negative effects on the environment [7]. If the number of connections with the maintained number of nodes is reduced or switched from direct connections to the hub system, the minimum number of required resources will reduce. If the number of hubs in the network increases, the number of connections decreases. Reducing the number of connections in the network increases the traffic flow per link, which increases the average vehicle capacity utilisation and resource utilisation in the system [54].

In his dissertation, author Kalantari [47] presents the possibility of implementing the FTN concept and the potential impact on the transport network. The identified challenges in foliated transport network design can be divided into three categories: transport planning and control, transport operations, and transport network optimisation. The planning and control category primarily relates to loading and routing capacities. Routing in the FTN concept, unlike individual systems, is dynamic and difficult to plan. It is necessary to preventively eliminate insufficient vehicle capacity and insufficiently filled capacity.

It is necessary to find a balance between utilisation and productivity on the one hand and system efficiency and customer service on the other. The potential of FTN can be realised within the limits of existing technologies. There is a need to provide solutions to optimise vehicle capacity and optimise resources within the hub terminal in terms of network optimisation. It is necessary to optimise the network in real-time and to dynamically control the distribution of freight between the different network layers. In transport operations, it is necessary to minimise the time needed for terminal operations in the hub. New identification technologies such as RFID can reduce terminal handling time and improve real-time planning and network control [47]. RFID technology provides detailed information about the characteristics of cargo, which influences more efficient cargo handling [7]. With the introduction of the FTN concept, the required number of resources in the network decreases at the same time as the minimum transport work increases, which is related to the growing average vehicle utilisation and the resource utilisation provided by the models [47].

In the FTN model, goods exceeding a full load must be collected before the goods in the direct shipments due to the operations on the goods. The forwarder needs to have the information at a very early stage to allocate the proper resources and again, information and time are key components. One problem is deciding when a load should be considered full and when goods exceed a full load. This is something that cannot be changed until information is available that reveals more about the characteristics of the goods. The organisation of FTN transport is dynamic and decisions need to be made as quickly as possible. It is also necessary to use real time cargo tracking technologies. In doing so there are also significant issues that need to be resolved in terms of standards and standardisation of tags and readers, standards that currently vary by country, supplier and technology [7]. Emerging Information Communication Technology (ICT) involved in horizontal interactions between different decision-makers could reduce the generalized costs of port operations. A large number of emerging technologies are aggregated into five groups according to [55]:

- Internet of Things (IoT) that allows exchanging information about the position, temperature, and weight of goods,
- Big Data (BD) that allow reconstructing the history of each container for security purposes,
- Blockchain (BC) also called the internet of value that allows carrying out monetary transactions between decision-makers,
- Artificial Intelligence (AI) that can allow allocating containers in an optimal position in yards,
- Digital Twin (DT) that allows simulating all the modifications of the interactions.

Studies show that FTN can be applied to existing networks with minimal additional investment in new technologies. Although new technology platforms and innovations would help in implementing the FTN concept, most of the identified potential can be exploited with existing technologies [56]. The potential for performance improvements identified and measured in the number of units, traffic capacity, and load factor is significant. Partial application is also possible, and about 80% of the potential can be exploited if about 20% of the system is available for this concept [47]. Foliated shipment control can significantly reduce the resource requirements and carbon footprint of LTL transport networks [57]. The main focus of foliated transport networks in supply chain management is on the flow of goods. But other layers, such as information and money flows, as well as responsibility, should also be included [58]. The most common optimisation criterion is economic. However, long-term and high-quality solutions require the introduction of other optimisation criteria such as technological, technical, environmental and many others. Multi-Criteria Decision Making (MCDM) is very effective in solving complex transport problems that involve several different criteria [59,60].

4. Conclusions

The transport system has a significant impact on sustainable development. Climate change is a crucial issue today, and accordingly, work should be done to reduce the negative impacts of transport on people and the environment. Optimising the transport system in the area of freight transport can significantly reduce negative impacts such as emissions, noise, traffic accidents, and more. In addition to environmental factors, it is possible to reduce the number of vehicles and personnel and ultimately reduce transport costs, which, in addition to global impacts, also satisfies transport companies and transport services users.

Foliated transport networks represent a concept that combines layered hub and spoke systems and direct connections with the aim of improving the technical, technological, organisational and economic efficiency of the transport system. The combination of these structures together with traffic management and quality information systems leads to better system performance than individual options. To identify the overall benefits of the model for the transport system, the foliated transport network needs to be considered from different aspects. These aspects can be divided into three main categories: organisation, economy, and environment.

The main benefits of foliated transport networks can be highlighted by analysing studies in this field. Firstly, the model is very flexible and offers high quality solutions for different volumes of goods; customer service is improved; transport costs are reduced through better utilisation and coordination of resources and more efficient freight handling; higher utilisation of vehicle freight space without a simultaneous increase in traffic, reducing the total distance travelled and saving time. It is a trade-off between some of the losses that occur and the overall benefits of combining the two models. Losses can be higher transport work and longer travel times related to additional manipulations in the hub. However, lower traffic work comes from fewer vehicles, higher resource utilisation, a variety of services and overall environmental efficiency, which can be considered as network benefits. The required number of resources in the network decreases simultaneously with the increase in minimum transport work, which is related to the growing average vehicle utilisation and resource utilisation. All this is achieved without compromising the overall quality of service. Foliated shipment control can substantially reduce resource requirements and carbon footprint.

The rapid development of information, communication and identification technologies is crucial for creating the technological basis for foliated transport networks. Planning tools must also be developed to improve the quality of the transport system itself. The potential for savings through the use of foliated transport networks, as presented in the works studied, justifies their development. The studies show that FTN can be applied to existing networks with minimal additional investment in new technologies. Although new technology platforms and innovations would help implement the FTN concept, most of the identified potential can be exploited with existing technologies.

It can be concluded that the key elements related to the FTN model are dynamic planning and control, optimisation and information systems. In such complex systems with many stakeholders involved, a holistic approach is required. The planning and control category primarily refers to loading and routing capacities. Routing in the FTN concept is dynamic and challenging to plan. It is necessary to preventively remove insufficient vehicle capacities and insufficiently filled capacities. The network in real-time needs to be optimised and the distribution of freight between the different network layers needs to be dynamically controlled. It is necessary to minimise the time required for terminal operations in the hub. Quality information systems are perhaps the most important component. Since the flow of information is critical for synchronise and connecting all parties, it is important to implement real-time information throughout the transport network to make the model as high quality as possible.

The papers in the field of foliated transport networks show that the authors are primarily looking at the concept of road transport. A small number of authors propose an application to rail freight transport. Given the negative impact of road transport on the environment, the congestion of road infrastructure, and the low cost-efficiency compared to other modes of transport, there is a need to explore areas that provide an alternative to road transport. Future research proposes the use of foliated transport networks in intermodal transport, as it is highly flexible and thus very competitive with road freight transport. The intermodal foliated transport network represents a complex transport model. This model combines different modes of transport in addition to the layered interconnection of direct links and hub and spoke. The problem is further complicated by the time component in hub terminals, including the time needed to consolidate freight and change transport modes. Optimal solutions and proposals for transport variants can be obtained through MCDM by applying appropriate methods based on the analysis of a number of quantitative and qualitative parameters to determine the optimal solution.

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