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The Impact of Differentiated Control on the Performance of Foliated Transportation Networks

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Abstract

The purpose of this paper is to explore the impact of differentiated control on the performance of a Foliated Transportation Network (FTN). The network models are evaluated through discrete event simulation. Empirical input data and parameters have been drawn from a case company. The study shows that moderately increased levels of differentiation improve the network performance. However diminishing returns with regards to increased levels of differentiation suggest that the necessary effort to account for the real time dynamics of the network is likely infeasible. Satisfactory results can be achieved utilizing a static approximation of the network dynamics. Substantial efficiency improvements are feasible to achieve using FTN logic which may be implemented with relatively small modification to existing systems and without the immediate need for extensive investments in new technology.

Keywords: Mixed model transportation, discrete event simulation, direct shipment, hub and spoke, Transportation network performance evaluation, transportation network dynamics.

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1 Introduction

Foliated Transportation Networks (FTN) is a concept where two or more systems are combined by way of foliation to create a new system that will outperform any of its constituting subparts in isolation (Kalantari, 2009). A special case of FTN, which is the object of the study in this paper, is that of a transportation network where a hub and spoke (HS) network is foliated over a direct shipment network (DS). The basic idea is to only ship fully utilized units through the DS layer of the network and routing the otherwise underutilized units though the HS layer. The physical network is not altered by the addition of a HS layer to the DS network. The change only means that some of the goods will be routed through the network according to the HS principle as opposed to a pure DS network where all the goods are shipped directly and the shortest way from the origin to the destination. Implementing an FTN instead of a DS network would potentially increase the overall network performance significantly (Kalantari and Medbo, 2011).

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A major concern regarding the control of which units to ship through which layer of the network is that of the level of utilization. How full is a full unit? Kalantari and Sternberg (2009) argue that because HS routing by default entails a longer route and additional handling, there exists a trade-off between enhanced capacity utilization and the additional cost of rerouting units through the HS layer. A hypothesis is put forth that real-time dynamic control of the routing of the goods is the most effective solution (Kalantari and Medbo, 2011, Kalantari and Sternbergs, 2009). In light of the current control practice in existing networks, this approach would likely require substantial investments in new technologies and processes.

One way of assessing the necessity of the hypothesized measures above is to investigate the impact of differentiated control on the performance of FTN. Kalantari and Medbo (2011) use a single static rule for deciding how to route the units through the network. The level of control could be increased by introducing differentiation. The purpose of this paper is to explore the impact of differentiated control on the performance of a Foliated Transportation Network (FTN). Seeing how FTN is a conceptual model still, assessing the impact of the level control necessary and its latent consequences for the performance of the network are key for evaluating the feasibility and potential of the concept.

In the following, the theoretical underpinning of the special case of the concept of FTN that is the object of study here will be discussed along with the operationalization of the concept of transportation network performance. This is followed by the presentation of the methodology and experiment design. Finally, the result and their implications are presented and discussed.

2 Transportation networks and network performance

Transportation networks are described in terms of nodes and links. Transportation network designs can be divided into two principle categories; (DS) direct shipment or (HS) hub and spoke (Crainic, 2002). In reality one does seldom find any pure systems (Crainic, 2002) and also in theory variations of the same two theme exists (Woxenius, 2007). The study of (FTN) foliated transportation networks require the revising of these two central concepts (DS and HS). Furthermore, operationalization of network performance is often problematic and non-trivial. The following aims to provide necessary coverage of these areas.

2.1 Direct Shipment Networks

In a direct shipment network all nodes are interconnected with direct relations. Direct relation means that the only nodes involved are the origin and destination, the goods are not consolidated along the way and that the transportation is independent of other O/D pairs (Woxenius, 2007) or in other words that the transport is dedicated (Crainic, 2003, Lumsden et al., 1999). A DS network is best utilized when the number of nodes in the network is limited, the demand for transportation in every connection is sufficient and the primary optimization parameter is time and flexibility.

A DS setup by default affords the shortest time in transit since the goods always travel directly, the shortest way and without any additional stops, consolidation operations or handling. A DS network is easily managed, due to the simple governing rules and the fact that transports are independent of eachother. In return, the DS setup requires a greater number of resources e.g. trucks in the system, leading to a lower transportation frequency. Also, its performance is dependent on sufficient volumes i.e. the demand in each relation must match the capacity reasonably well in order to achieve acceptable levels of resource utilization rate.

2.2 Hub and Spoke Systems

In a HS setup, all the nodes are only interconnected with a/the hub and in cases where more than one hub exists all the hubs are also interconnected (Crainic, 2003, Woxenius, 2007). A hub network creates a larger spatial coverage and high transport frequency for the network since the volume that flows between the O/D pairs does not need to be very large to be included (Woxenius, 2007). Other advantages of the HS setup is high resource utilization rate, both regarding time and capacity, lower number of resources in the network and more levelled flows (Lumsden et al., 1999). A HS setup is preferred in a network with a vast number of nodes, where aggregation of demand is necessary to attain adequate flow and the primary parameter of optimization is resource utilization and coverage (Bryan and O'Kelly, 1999).

On the other hand, deliveries in a HS network almost never run the shortest way; they require coordination with flow between other O/D pairs and require complementary handling which all lead to more time in transit. The extra handling puts additional strains on transhipment terminals and also increases the risk for lost and damaged goods. The required coordination increases the complexity in the system and is more difficult to manage.

2.3 Foliated Transportation Networks

FTN can be describes as a DS network where only “full” units are sent directly and all units that are not full are consolidated in HS sub-system(Persson and Lumsden 2006, Bjeljac and Lakobrija, 2004). As illustrated in figure 1, full units would be dispatched in DS layer of the network (bottom layer) and the units that cannot be filled in the HS layer (top layer). It is presupposed that the transport demand in most of the relations is large enough that more than one unit is required. This would imply that the units that would possibility be eligible for consolidation in the HS layer are the last units in each relation. Relation directionally dependant origin-destination (O/D) pairing e.g. (A) to (B) is not the same relation as (B) to (A).

Given this presupposition, the only logical setup would be that of foliating a HS over a DS network and any comparison of performance will thus have to be done between FTN and DS. The logic behind this choice is that, for one, the improvement in performance that is previously identified stems from reducing the number of links in which underutilized units may be sent. Such reduction is only possible when foliating a HS over a DS network and not the other way around. Secondly, if the volumes of goods being transported through the network are limited enough to warrant that application of pure HS network, other concepts, e.g. short cuts by Lumsden et al. (1999) or similar modifications in Woxenius (2007), would be the more logical choice.

In an FTN, even though the network is regarded as consisting of two different layers in its management, the physical network is unaltered and can be adequately be described as a DS (Kalantari, 2009). Lumsden et al. (1999) describes a similar approach where the basic structure is a HS setup that can be shortcut with occasional direct relations when possible i.e. when there is enough demand to fill a whole unit in any O/D pair relation.

Kalantari and Sternberg (2009) raise the issue of when a unit can be considered full. They hypothesize that likely, there does not exist a universal level of utilization or cutoff value, that would suffice for identifying a unit as full in any given situation; rather this ought to be dependent on the real time dynamics of the network and the distribution of goods volumes and transportation demand within the network.

The rerouting of goods via the hub is by default connected to the cost of traveling a longer route than the direct routing and also the cost of an additional deconsolidation/-consolidation operation. Furthermore, routing an additional unit via the hub can potentially disrupt the balance of inflow and outflow from the hub or creating critical levels of congestion and thereby deteriorating the effectiveness of the network as a whole.

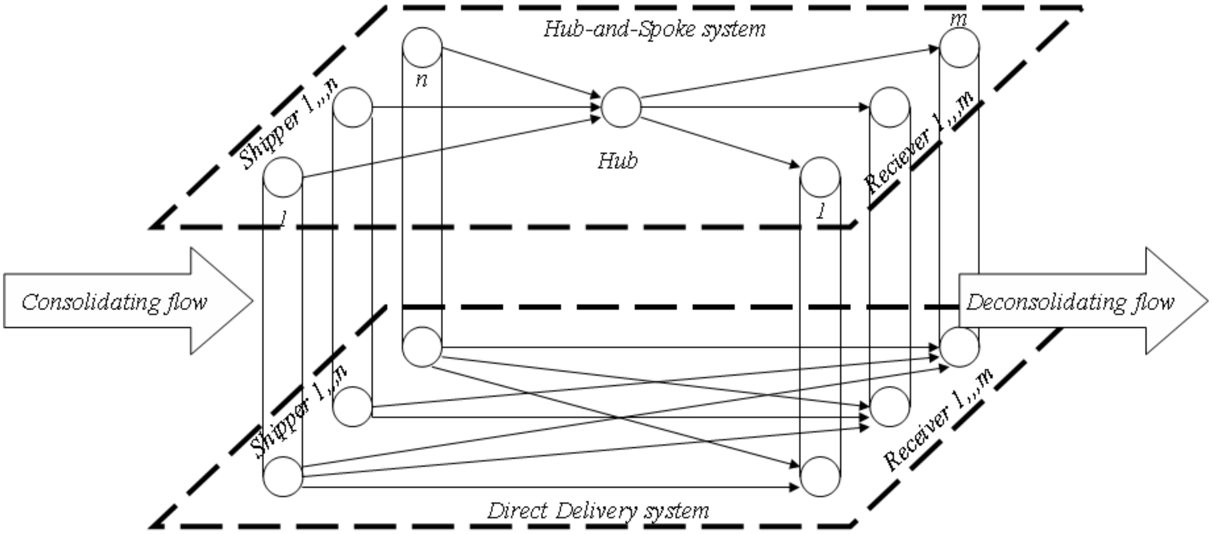

Figure 1 A representation of the FTN model (Persson and Lumsden 2006). The full units are sent directly in the bottom layer of the network (DS) and the last units in each relation that is not sufficiently utilized will be consolidated in the top layer (HS).

The performance improving potential of FTN has been addressed by Kalantari and Medbo (2011). The study shows that the FTN network can be significantly more efficient than a DS network without any deterioration of the service quality, or effectiveness of the output. However, that model is based on a single level of utilization, or cutoff value, as the deciding factor for routing units via the different layers of the network. The level of control has been hypothesized to have a significant impact on the performance of the network (Kalantari and Medbo, 2011, Kalantari and Sternbergs, 2009) with the best possible scenario being where the allocation of capacity to the different layers are based on real time dynamic control. This paper sets out to explain the impact of enhanced control.

2.4 A construct for measuring transport efficiency

Network performance consists of the two components of efficiency and effectiveness (Mentzer and Konrad, 1991). Efficiency encompasses utilization and productivity (Caplice and Sheffi, 1994). Utilization measures “input usage” and is a ration of actual and nominal input e.g. utilized and available capacity and productivity, which measures transformational efficiency is a ratio of actual output and input e.g. transport work and traffic work. Effectiveness is a measure of quality of process output and can be expresses as a ratio of actual and nominal outputs e.g. a ratio of number of shipments delivered on-time and the total number of shipments. Performance, which is compound of efficiency and effectiveness, can be considered improved if effectiveness is sustained or improving at the same time as efficiency is increased e.g. in the case of the study of the performance of FTN in Kalantari and Medbo (2011).

McKinnon (2010) surveys the prevailing measures for the indication of freight transport efficiency. Efficiency is accordingly expressed in loading factors (ratio of actual and maximum) based on units such as weight, volume, deck-area coverage and tonne-km or the level of empty running; none of which are very good measures for efficiency if used in isolation. This is both due to issues regarding how to measure and the construct of the measure.

In the case of empty running, for instance, the issue of what constitutes an empty unit is difficult to answer without the measure becoming arbitrary or less than useful. Examining the loading factor constructs, it becomes clear that measure can become misleading regarding what is aimed to assess i.e. transport efficiency.

For instance, some systems such as waste management, farming, mining and forestry transports are by default not able to achieve a higher loading factor than 50% when measured on the round-trip. Secondly, the efficiency transportation is heavily dependent on economies of scale. Using a loading factor measure in isolation would erroneously indicate a suboptimal system consisting of a fleet of smaller units with higher utilization rate as more efficient than comparable one with sufficiently large units with lower rates of utilization. This flaw in the construct can be partially remedied if the lading factor metrics are used in combination with other complementing indicators such as the number of units, traffic work and/or transport work.

Moreover, as Nanos-Pino et al. (2005) point out, the matter of measuring efficiency is further complicated with the fact optimum resource utilization from a business perspective does not always perfectly overlap with the optimum physical resource utilization rate. This complication maybe at least partially circumventable if one would regard the physical KPI that drive cost and revenue separately; such as transport work and traffic work that drive revenue and cost respectively.

When it comes to transport work another crucial distinction is in order; namely that of the perspective of the shipper and the carrier. The transport work of the network can be divided into two types: internal and external. The external transport work is the total number of tonne-km that is demanded by the shippers in order to satisfy their transport needs i.e. the product of the goods volume and the O/D matrix. The internal transport work is the actual number of tonne-km that is produced by the carrier in fulfilling the transport assignments. This distinction is readily apparent in the case of a pure HS setup where almost all of the consignments (barring the ones that have the hub location as their final destination) will lead to a higher internal transport work than what the shipper is demanding and subsequently is willing to pay for.

The traffic work is the total amount of vehicle capacity kilometres that is produced in the network during a period of time (also measured in tonne-km). The quota between external transport work and traffic work is a suggested representation of transportation performance for a given network, and a given period in time (analogously a given demand). The traffic work is related to the external transport work because that is the main purpose of the transport, to move goods according to a predetermined O/D matrix.

n represents all possible relations in the transportation network. D_i is the nominal distance for relation i and d_i is the actual distance transported. q_i is the transported quantity in the relation i. C_i represents the capacity that is used in each relation i.

n = Number of relations in network
D_i = Nominal distance for relation i
d_i = Actual distance transported in relation i
q_i = Transported quantity in relation i
C_i = Vehicle capacity used in relation i

$$\text{Transport work}_{\text{External}} = \sum (D_i\, q_i)$$
$$\text{Transport work}_{\text{Internal}} = \sum (d_i\, q_i)$$
$$\text{Traffic work} = \sum (d_i\, C_i)$$
$$\text{Transport efficiency} = (\sum (D_i\, q_i)) / (\sum (d_i\, C_i))$$

The transport efficiency is thus defined as the quota between the external (nominal) transport work and the performed traffic work, for a specific time period (i.e. demand). This transport efficiency construct is subject to the same flaw (risk for sub-optimization) as other loading factor measures discussed above. However, when comparing two setups of the same system, where the unit size is constant, the flaw in the construct will not become an issue.

At the same time, it is more valid, useful and robust construct than the loading factor in McKinnon (2010) due to the fact that this construct penalizes deviation from the shortest possible route. To illustrate, consider any pure HS network as compared to a DS. Using a straight loading factor in isolation would yield that the HS setups is preferable to a DS one in almost every case, where as it is readily apparent that this cannot be the case.

For this reason, choosing this construct for measuring the network performance in the experiment presented below is an appropriate choice. Network performance will be measured based on the above mentioned construct of transport efficiency i.e. the ratio of external transport work and traffic work. The condition of sustained effectiveness is met in the experiment setups wherefore any improvement in efficiency is analogously an increase of the performance.

3 Methodology

This study makes use of empirical data collected from a representative company to serve as input and configuration parameters in an experimental discrete event simulation model. The choice of simulation was an obvious one based on the fact that the systems studied are complex and dynamic where experimentation in a real system would be too expensive. Simulation allows for testing new procedures, policies or methods (Banks et al., 2001); a quality that has had a decisive role in selecting simulation as the method of choice. Furthermore, the choice of method enables the consideration for both the discrete and stochastic nature of the studied system. The model represents an ideal typical foliated transportation network in order to compare the performance of the different network setups with regards to transportation efficiency by executing experiments in the model environment.

The data set has contained the daily volumes (payload expressed in kg) in each relation of the network. A sample of eight consecutive weeks (40 working days) has been drawn from the provided data. The data has been verified through a comparison with aggregated data and historic data obtained from different sources. The chosen period of time is considered representative as the total flow exhibits signs of high stability. The empirical data has been used for deciding the physical network setup, i.e., the number and position of terminals, and to create theoretical distributions for the daily volume of goods in each of the relations of the network. The performance, operationalized as transportation efficiency, has been measured mainly using the construct for efficiency presented in (2.4).

3.1 The simulation model

The empirical data collected from the case company has been used not to simulate the operations of the case company in and of itself but rather to provide representative input parameters for the comparison of two general models i.e. a direct shipment network and an FTN. The simulation study follows the steps proposed by Law (2001a). The input data analysis, model descriptions and validation aspects of the simulation study will be discussed in detail below.

3.2 Input data analysis

The sample data was checked for extreme values, autocorrelation, variance and other anomalies that would be in contrast to the other sources of data i.e. the aggregated data for the same period, historic or qualitative data (Leemis, 2004). None of the tests reviled any reason to doubt the correctness of the data provided.

A randomly selected sample of 10% of the relations where selected and tested for fit for theoretical distributions. These test where performed in Expert Fit software called StatFit (Law, 2001b). None of the tests rejected a lognormal distribution and over 50% of the sample was found to have the best fit to lognormal. Based on that, the daily volume of goods distribution of all relations was assumed to follow a lognormal distribution. In the same fashion the theoretical distribution that best fit the size of the single shipments where estimated.

3.3 Model description

The modelled network’s structure i.e. number of terminals and the distance in between them has been mirrored from sampled data from the case company yielding a network of 24 terminals i.e. an O/D matrix of 210 relations. Goods in system have been modelled as weight measures with direction i.e. an origin and a final destination.

In all setups goods are served by the FIFO principle thus there is no sophisticated selection criteria that would allow optimization in grouping different consignments to a particular loading unit. The model is designed so that each model run is one day’s worth of transport, one way. This means that fleet management aspects and return flow of e.g. resources and personal is not included in the models.

The model can be described as a DS network where there is a hub terminal designated in the design. For the decision of which terminal to act as hub, a gravity model is used. Random generation of goods volumes in every direction and its division to individual consignment is performed at the start of each run. Goods are then loaded on to the trucks and delivered according to the DS principle until all the goods in one relation are delivered or that the remaining amount of goods in the relation are not sufficient to fill an entire unit. This is accomplished thusly: in every relation before a truck is to be loaded, a test is performed to see whether the remaining amount of goods is more or less than what would take to fill an entire unit. If the amount is more than the capacity of one truck, the goods are loaded and shipped directly. However, when the remaining amount is not sufficient, the goods are loaded onto trucks that have the hub terminal as the intermediate destination. Also all the goods destined for the hub terminal as their final destination are loaded on the same trucks without discrimination or separation. The "hub-trucks" depart then after all DS trucks have left their origin terminals. The cutoff value for what constitutes a full truck is subject to variation and differentiation between runs and relations according to the experiment design.

The content of the hub-trucks are upon arrival to the hub terminal then unloaded sorted and reloaded on trucks and sent to their final destinations. The goods that have had the hub terminal as final destination are not further handled in the model. The trucks arriving to the hub terminal are also utilized for shipping goods from the hub terminal to the final destinations. Additional trucks are allocated i.e. in effect "created", only if the need has risen.

3.4 Validation

Banks (1998) outline eight different validation strategies for a simulation model. Some of the strategies are not applicable because they require testing the results in comparison to historic outcome or a specific existing physical system. The model in this study is to be considered general and not an emulation of a specific system. This limits the validation strategies that are applicable to; face validation, sensitivity analysis and validation of conceptual model assumptions.

Face validation is implicitly performed throughout the modelling and execution of the simulation. To this end, some dummy variables and control statistics have also been inserted to/extracted from the model. Several sensitivity analysis have been performed, both designed and via the embedded functionality in the simulation software. The results of the sensitivity analysis do not add any concerns for the validity of the model. Furthermore, the system input, conceptual model and performance has been compared to and confirmed by the broad range of qualitative data. Also previous studies based on the same system and existing theoretical knowledge offers support for the validity of the models.

Any validation effort becomes more complicated when it regards system setups or policies that are yet not in effect. The logical inferences with regards to the generative mechanism that would explain the outcome is used as means to elevate the validity concerns that stem from this condition.

4 Experiment design

The fundamental idea behind the experiment is to investigate if the model design in Kalantari and Medbo (2011) where a single static cutoff value is utilized for routing volumes through the HS layer of the network can be improved by employing differentiated control i.e. utilizing different cutoff values for different relations. The cutoff value denotes the minimum fill rate at which a unit is consodered fully utilized e.g. here at 75% (in accordance with the previous study of Kalantari and Medbo (2011)). Ideally, a model in line with the conceptual design of FTN in Kalantari and

Sternberg (2009) where the cutoff is to be dynamically calculated in real time would have been used. However, this setup would in effect require that the distribution of goods within the two layers of the network would need to be optimized and reconfigured upon the entrance of any new order in the system.

For the benefit of comparability the size and configuration of the network model in this study is mirrored from the Kalantari and Medbo (2011) model. Given the size of the network (210 relations), none of the available commercial optimization software were powerful enough to accomplish this feat for a network of this size. The hypothesis that a real-time dynamically controlled network would be the most efficient setup is based on the identified trade-off between capacity utilization and cost incurred due to the inherent detour that allocation to the HS layer entails (Kalantari and Sternbergs, 2009). For any given transport network, the external transport work will be fixed i.e. independent of how the demand is fulfilled. The traffic work, however, is dependant of how each truck is routed through the network. This means that the impact of routing goods from individual relations via the hub is dependent on the extent of the additional distance that trucks need to travel that the hub routing would entail. Based on this circumstance, a penalty cost for detour can be modelled and used for differentiated control of the foliated transportation network.

4.1 Modelling the penalty cost for hub detour

To circumvent the obstacle of network size, and still reach a satisfactory level of differentiation in control (i.e. cutoff values for different relations), the relations were categorized based on a hub distance deviation index (HDI). The index is calculated as the ratio of the distance that needs to be travelled via the hub (HS route) and the distance traveling the shortest way (DS route). By employing the performance construct presented in (2.4) that penalizes deviation from the shortest way, the network can be controlled using different rules/cutoff values for different relations or categories of relations.

When HDI is calculated for all relations, relations are categorized using scatter grams where relations with similar HDI were grouped together and subject to the same cutoff value i.e. differentiated controlled as compared with previous setup where all relation were controlled uniformly. Doing this enables both differentiated control as well as consideration for the trade-off between capacity utilization and traffic work produced. To reiterate, the cutoff value is the load factor value at which a truck is considered full and consequently sent directly and below which units are considered not full and are sent to the hub for further consolidation.

4.2 Evolution of experimental configurations

The initial grouping yielded 12 different categories of relations. The categorization is ultimately judgement based and is a result of how relations with similar HDI are naturally clustered together on a scatter-gram. The largest category consisted of 48 different relations and the smallest one of two (2). The rest of the categories consisted of between 8-20 relations. The network is then optimized using Optquest ™ - an optimization suit included in the Simul8™ software - maximizing network performance and with regards to cutoff value for different categories. After completion, the cutoff values of the 12 categories yielding the best result was examined. Categories where the cutoff value did not differ more than 5% were merged, and the new configuration with fewer categories was set up and optimized. This procedure was repeated until saturation was obtained i.e. no two categories had the same cutoff value give or take 5%. The 5% limit is judgement based and aims to choose a limit that would be operationally feasible to measure and control. The largest single consignment in the system corresponds to approximately 2% of capacity and one full pallet would roughly be 5% of capacity. These values are extracted from the empirical data and contributed to deciding on 5% as the minimum distinguishable difference.

The logic of this process is twofold. For one, and as indicated above, the accuracy with which a unit's load factor can be measured and controlled in an operational setting is likely lower than 5%. Secondly, the additional computational power necessary for optimizing over an additional category grows exponentially which makes is pertinent to investigate the impact of reducing the number of categories i.e. differentiation, on the network performance. Basing the categorization on HDI yields two distinct benefits for the experiment at hand. Firstly, the number variables i.e. cutoff values, are reduced from 210 to levels where they can be handled given the model and tools for analysis that were available. Secondly, even though the model is not controlled dynamically at real time, the level of control is increased significantly from what was the case in the previous study cited. Furthermore, this approach is compatible with the nature of the construct used for assessing the transport efficiency (or performance of the network) presented above (2.4).

The experiment yielded 6 different setups. The two extreme configurations i.e. 1 cutoff value for all the relation in the network (no differentiation in control) and 12 different categories (highest level of control differentiation in this experiment), were a priory chosen. The other 4 configurations consisted of 8, 7, 6 and 5 categories. The number of categories was reduced in the same way as explained above iteratively and stepwise until saturation was reached. Each simulation trial consisted of 5 runs which is enough for obtaining results with 99% confidence interval. The optimized outcomes of all the network configurations were compared in a single factor Anova test with 95% confidence interval.

5 Results

The results from the all the trials (using cutoff values from the best trial i.e. after optimization), expressed in the ratio of external transport wok and traffic work, are summarized in table 1 and figure 2. Table 1 also includes the metric total number of trucks as a control for sub-optimization. As evident by the result and argued above (2.4) when the size of the units is uniform, the presented construct for efficiency will not produce suboptimal results.

A ratio of (1.0) would mean that a unit that is fully utilized has driven the shortest way to satisfy a given transport demand. Deviation from (1.0) is caused by not driving the shortest possible way and/or underutilization of loading capacity. The outcome from every relation is used to derive a single figure for the performance of the entire network.

The results from the DS configuration are included as a point of comparison so that the efficiency potential of FTN, even when governed statically and without attempt to optimize or differentiate is none the less conveyed. The results from the DS network are not further included in the analysis as they fall outside of the purpose of this paper and is therefore not included in figure 2.

Table 1 The results of trials from all different network configurations. The table shows that foliation yields a significant performance improvement. Differentiated control contributed to enhancing this impact at marginal but statistically significant levels.

	DS	*FTN_1*	*FTN_5*	*FTN_6*	*FTN_7*	*FTN_8*	*FTN_12*
Transport efficiency[1]	85.8%	94.3%	95.6%	95.7%	95.8%	95.8%	95.5%
Standard deviation	0.34%	0.31%	0.26%	0.06%	0.10%	0.11%	0.21%
Number of trucks	706	614	612	612	613	613	614
Standard deviation	13	14	14	14	15	15	15

Figure 2 illustrates the results of the experiment graphically using a box and whiskers diagram. The horizontal axis is discrete and denotes the different levels of differentiation id control and the vertical axis is continuous and denotes the single value appraisal of network performance. It should be noted that even though the identified difference attributed to differentiated control is statistically significant, it is not very large. This should be obvious upon examining the scale of the vertical axis where each step (illustrated with horizontal lines) is only (0.001).

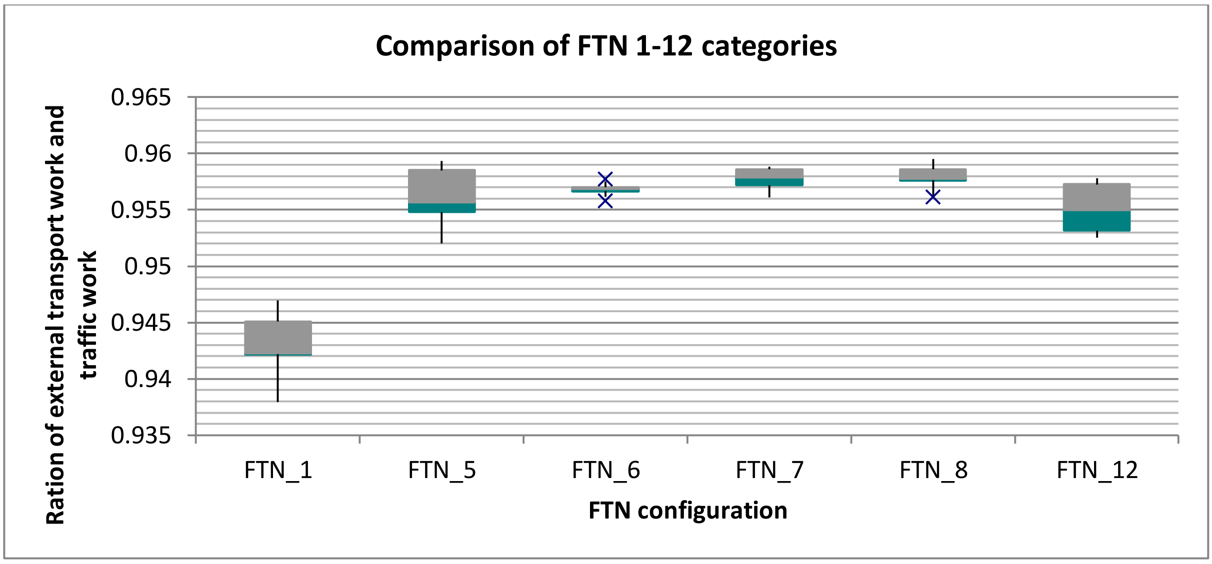

Figure 2 Box and whiskers graph of the results of the trials of all FTN configurations illustrating that differentiation increases performance at a statistically significant level at the same time as the level differentiation does not impact performance.

The Anova test revealed the means are different at 95% confidence interval. Both post hoc tests, Scheffe and Tamahane, yielded the same result which is that the single category configuration of the network is different from all others. The means of the configuration using 5-12 categories are the same. The post hoc tests are also performed at 95 % confidence interval. The test of homogeneity of variance yielded a value of 0,048 which is not a very clear cut verdict for the assumption of homogeneity. For this reason both (assumption of homogenous data) Scheffe and (assumption of

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[1] Expressed as the ratio of external transport work and produced traffic work (see 2.4).

heterogeneous data) Tamahane post hoc test were performed. Both tests yielded identical results.

6 Conclusions and future research

It is clear that differentiating the cutoff value for directing the flows of goods between the two layers of the network has a statistically significant effect on the network performance. However, the level of differentiation does not need to be very high to reach this potential. More importantly, the results indicate that more is not better. In fact, there is no statistical difference between the performances of the configurations with 5-12 categories. This conclusion rests on two observations.

First, the effort necessary to optimize the distribution of goods across the network layers grow exponentially with each additional level of differentiation and quickly surpassing what would be operationally feasible. It is highly doubtful that the additional effort needed can be motivated with the additional potential that can feasibly be realized. Already at lower levels of differentiation, the diminishing returns of additional efforts are apparent. The relatively meagre outcome of the most differentiated setup i.e. 12 categories, is an indication of the limits of the optimization suit employed in this study. Moreover, even this result was made possible through an optimization process that required runs over a period of time that would be operationally infeasible (Several days). Naturally this time can be shortened if higher computational power were to be utilized. The point remains however, whether the additional cost of this operation would be covered by the additional improvement of network performance.

Secondly, the maximum theoretical potential that remains at this point is limited. This is further indication of the diminishing returns of real time dynamic optimization or even continued differentiation. These results lend support to the “low hanging fruit” phenomenon hypothesized in Kalantari and Medbo (2011).

The sensitivity of the results was tested i. a. for the distribution of the size of the consignments and the mechanism used for grouping relations into categories (i.e. HDI). The tests did not reveal any cause for concern regarding the validity of the results. It can be concluded that future studies of networks of comparable size, probably can assume the volume of goods as continues without deteriorating the validity of the results.

The feasibility and potential of FTN has been studied in several studies (cited above) with encouraging results. Furthermore, the it is clearly indicated that the FTN logic may be implemented with relatively small modification to existing systems and without the immediate need for extensive investments in new technology. The continuation of this research should be directed towards issues of direct operational importance.

For one, the time distribution of placed transport orders and arrival and departure of goods to the origin and destination terminals needs to benefit from future attention of studies. This is important for identifying the triggers and decision criterion regarding which individual consignments that are to be routed through the different layers of the network, given the volume amount. Furthermore, operational processes that need to be designed to facilitate speedy expedition of goods through terminals such as goods segmentation need to be further studied.

Some of the novelty of the concept of foliation pertains to the fact that two different network structures or control principles (DS and HS) are simultaneously employed in a single system; resulting in a network the outperforms any network operating only according to any one of the constituting layers. In principle, this idea is not limited to just the foliation of DS and HS network. One interesting avenue for future research might be the study of other dimensions that might benefit from the introduction of foliation logic. Foliation of different modes or the concept of co-modality might turn out to be on such avenue for future research.

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