Limburg

Parcels currently shipped by web shops seem to be packaged rather inefficiently. This inefficiency can be measured rather easily by comparing the volume in a parcel that is consumed by goods, to the volume that is used up by empty space (e.g. air).

The average parcel size in e-commerce shipments – a variable in coping with congestion in carrier networks?

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MANAGEMENT SUMMARY

Parcels currently shipped by web shops seem to be packaged rather inefficiently. This inefficiency can be measured rather easily by comparing the volume in a parcel that is consumed by goods, to the volume that is used up by empty space (e.g. air). When the product makes up for a low percentage of the total parcel volume, this is to be seen as a low volumetric utilization with regards to space consumed by the parcel. Yet in transport networks forwarding these parcels, weight and volumetric dimensions are generally considered significant determinants of transport movements, hence for also kilometers, CO_2 emissions, and cost. In recent years, technologies have emerged which allow for parcels to be created in alignment with the measurements of goods to be packed, improving the volumetric utilization of a parcel.

Therefore, one aim of this paper is to assess the potential impact of made-to-measure packaging on the volumetric utilization of parcels created. The ultimate objective is to assess whether the volumetric savings attainable can lead to efficiency improvements in parcel carrier networks forwarding these shipments. Potential gains can be a reduction in kilometers or transport intervals in a network. Currently, parcel networks are subject to congestion due to an immense demand growth, with congestion being defined as stress placed upon a network by means of more demand than it could normally cope with. This is currently the case for networks like PostNL and DHL.

To measure the average volumetric reduction attainable, a sample was conducted at a fulfilment provider. Analysis has shown that the average parcel size can be reduced by at least 20% by means of currently available made-to-measure packaging technology.
To assess the effects of this volumetric reduction on parcel carrier networks, the network structure has been divided into three transport sections allowing for detailed analysis: Parcel collection, inter-hub transport, and last-mile distribution. Interviews with two major carriers have been conducted in order to discuss the effects of volumetric reduction in these sections. This has been done by discussing volumetric changes based on network variables (factors), not all of which have proven to be relevant determinants for efficiency. The most important factors counteracting efficiency improvements due to volumetric reduction are (collection) time in parcel collection (as a result of delivery time requirements) and drop rate in last-mile distribution. While a slight increase in network efficiency is visible in these transport sections, this does not ultimately lead to less vehicle movements, particularly in last-mile distribution. A significant effect however can be observed in inter-hub transport. Multiple carriers have confirmed that 20% reduction in total kilometers is feasible. They also confirmed that they see the most potential in this transport section, as a higher volumetric utilization of vehicles will lead to (1:1) fewer transports and in turn reduce logistics costs. A precise simulation of these findings will be a topic for future research.

Keywords: E-Fulfilment, Distribution, Carrier networks, Congestion, Packaging, E-Commerce, Netherlands, Efficiency, Cost Drivers, Developments.

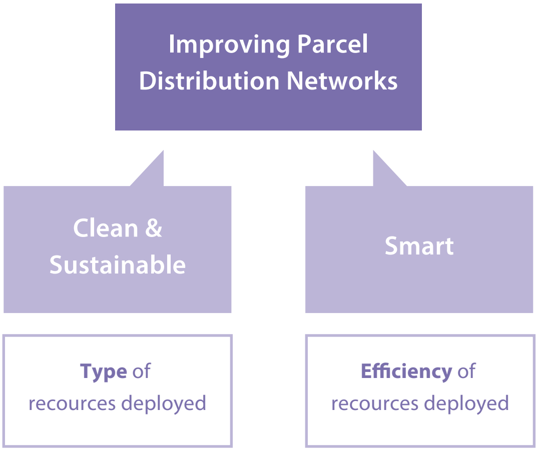


Figure 1 Opportunities for future improvements

Introduction

For almost two decades now the growth of online commerce has outgrown retail sectors. With an average annual growth of 15% (Ecommerce Europe, 2017), disruptions in consumer purchasing habits are stressing many industrial branches. While order processing, and to a certain extent order fulfilment, seem scalable in regards to these immense growth figures, the delivery of goods poses a number of problems as shipments need to be consolidated, yet represent singular shipments requiring individual treatment. This is why parcel carriers and their delivery vehicles are often seen as the root cause for a number of societal problems. Excessive use of transportation resources is required to forward today's parcel volumes. Moreover, delivery vehicles appear to be responsible for a significant share in total emissions. Up to 35% are caused by logistic transports (Dijkhuizen, 2017). An additional strain is put on parcel networks by means of their annual growth of about 12%, up to 40% for some networks. During peak periods, this leads to network congestion, meaning that parcels cannot be forwarded due to capacity limitations of a particular network. This has been observed in an increasing number of networks in recent years (NOS, 2017).

A general consensus for solving these issues (Figure 1) is to create *smarter*, *cleaner*, and more *sustainable* solutions for future distribution networks (Ploos van Amstel, 2015). *Clean* and *sustainable* solutions can for instance be achieved by introducing new transport modes (e.g. cargo bikes) and using renewable energy sources (e.g. electrification). *Smart* solutions however will lead to intelligent, hence more efficient use of existing distribution infrastructure. While steady progress can be observed in regards to the first, this does not appear to hold true for the latter. Even with new transportation modes and power sources, parcel distribution processes have remained largely identical in their execution in recent decades. Particularly the volumetric utilization of current transport capacities available is expected to be rather unfavorable, mainly due to an poor ratio between space consumed by *actual* goods and more spacious secondary packaging (*the parcel*). The *real* utilization, for instance of a truck, is not given by the measurements of the parcels transported, but rather the measurements of the goods in these parcels. Furthermore current fleet utilization may even become worse due to developments such as same-day propositions, requiring shorter transport intervals. Few tangible solutions to this problem have been proposed so far.

One way to increase the efficiency of distribution networks might be a reduction in average parcel size by means of more efficient secondary packaging (*parcels*). Identical content could be distributed while consuming less volume (*space*) within these networks. A decline in average parcel size seems achievable, as air is the dominating element in many parcels, representing up to 95% of the content.

Currently however it seems unclear whether there are opposing effects counteracting an increase in efficiency in these networks, ultimately preventing volumetric savings to take effect. A carrier might for instance switch to a smaller vehicle instead of reducing the number of transports when volumetric demand decreases, causing only a minor decrease in cost and emission, and no reduction in rides.

In order to clarify dynamics such as these, this paper aims to assess the efficiency-impact of a reduction in average parcel size on parcel networks. Data on average outer parcel dimensions in relation to the volume consumed by actual content in these parcels serves as an indicator for an achievable volumetric reduction. Subsequently, factors potentially opposing these savings are examined. The paper is based on explorative research and executed in close cooperation with a number of large online retailers, fulfilment companies and parcel carriers. Literature on carrier network structure is used to validate practical findings.

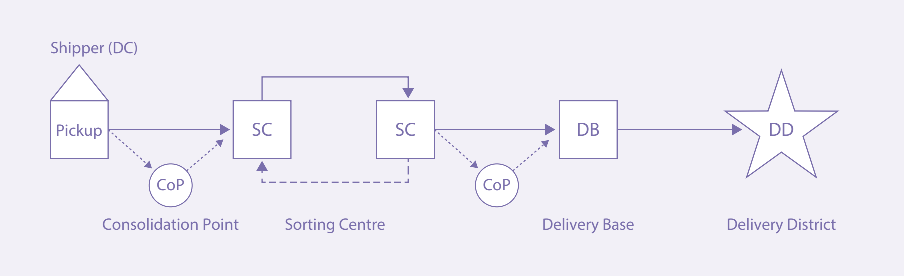


Figure 2 Basic parcel network structure (based on Baumung et al., 2015).

Carrier networks – an overview

In order to create an understanding of parcel networks, this section will focus on providing an overview in regards to crucial elements and mode of operation in parcel networks. Baumung, Gündüz, Müller and Sebasian (2015) discuss the variety in components and subnetworks of parcel distribution networks by means of a basic process sequence (Figure 2). The origin of every network lies in the pickup of parcels, mostly at the distribution facility of an online retailer. Within lower intensity networks, parcels are redirected through local consolidation points, bundling parcel volumes and increasing the utilization in subsequent transport. This transport will forward parcels to a proximate sorting center (SC) allocated to the region of their collection. This process, from pickup to the first SC is called parcel collection. SCs then represent the main consolidation infrastructure in order to bundle parcel flows to the different areas covered by a network. In these SCs, mostly positioned on a regional level, parcels are sorted based on the SC allocated to their destination area. The coverage of SCs however is generally fairly low as they operate on a high consolidation level. DHL Germany for instance operates 34 facilities of this type nationwide (DPDHL, 2017).

Once initial sorting has taken place, parcels are forwarded from SC to SC by means of **inter-hub transports**. As consolidation here is significantly more intense compared to parcel collection, these transports are executed by larger, often scheduled, trips between SCs, generally involving high-volume transport modes and vehicles (e.g. trucks). Once a target SC has been reached, a second sorting process deconsolidates volumes for transport towards less regional, more local delivery bases (DB). The core function of a DB lies in servicing local surroundings by means of operating a number of individual delivery districts (DD). Operational execution in these DDs is then taken care of by means of delivery vehicles, dropping shipments at their destination address. This process, from DB to consignee address is defined as **last-mile distribution**.

Hence, in order to clarify the efficiency gains attainable by means of volumetric reduction in parcel size, this paper will adhere to the basic transport sections discussed: parcel collection, inter-hub transport, and last-mile distribution.

The average volumetric reduction attainable

Brinker and Gündüz (2016) indicate the importance of efficient packaging by companies in order to save material and transportation costs. Reducing empty space within parcels, consequently making them smaller, means that less space is required in storage and transport. However, it is not clear to which extent parcels can be reduced in size. In order to measure the potential savings in volumetric reduction, a sample has been taken at a multi-client fulfilment company serving a variety in e-commerce segments. This has been done with the aim of gathering information on current parcel utilization, and also assessing which factors influence the current utilization of parcels. The sample size gathered was n=131 parcels, containing 346 items. Width, length, and height of every article were measured and recorded. The company in question utilizes fourteen standard boxes, three types of mail bags, a variety of protected mail envelopes, or ships the goods in their primary package with an added plastic layer for protection.

In the sample taken, parcels were utilized for 39.4% on average, leaving 60.6% of the volume empty. This empty space is filled with packing materials ranging from cardboard to plastic filling material or air cushions. Figure 3 indicates that one factor influencing utilization is the number of articles packed in a parcel. These two variables exhibit a direct correlation, allowing for the conclusion that utilization is higher when more articles are packed in a parcel, however the significance of this correlation has to be proven in future samples.

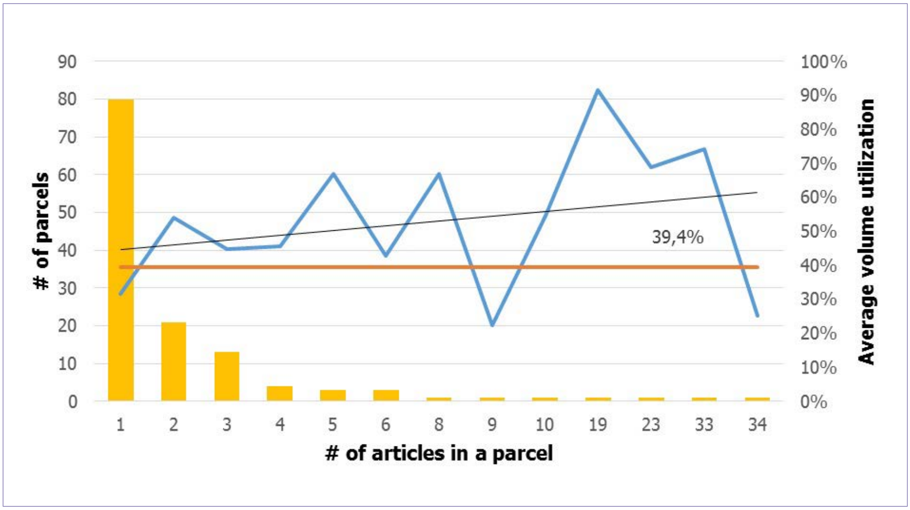


Figure 3 Average volume utilization.

Orders shipped in their primary package naturally have a utilization of 100%. In this case the primary package is identical to the secondary / transport package. When excluding these nine orders from the calculation, average volumetric utilization drops further to 34.9%.
Besides generic utilization of parcels, a variety in different market segments was analyzed to see whether there is a variance between different segments. Products were categorized as follows: Consumer electronics, food/near food, health & beauty, home & garden, home appliances, clothing, shoes & personal lifestyle, sports & recreation, and others as used by Thuiswinkel in 2016). Only 5 out of 131 (3.8%) parcels contained products from two market segments. All other parcels may still contain multiple products, however belonging to the same segment. Figure 4 shows the average utilization per parcel for every market segment recorded.

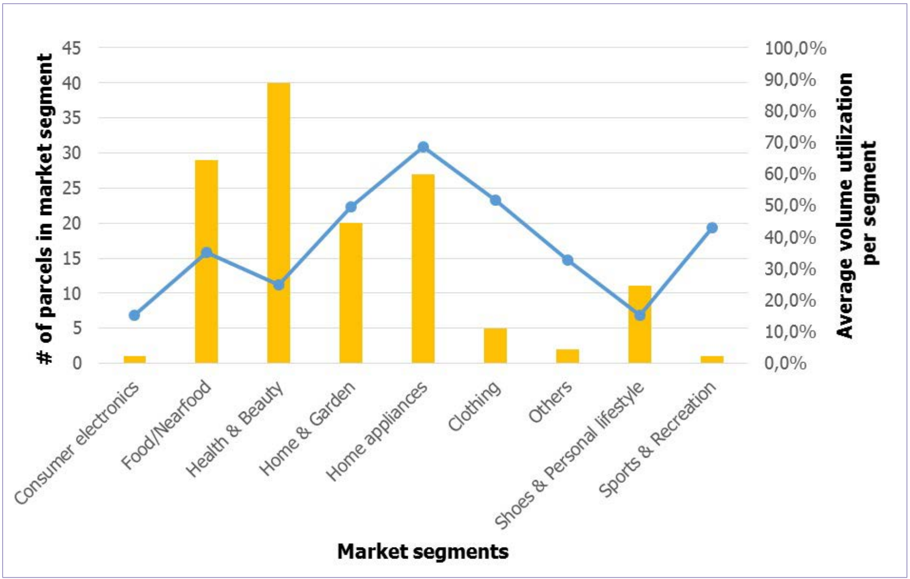


Figure 4 Volume utilization per market segment.

Unfortunately not enough data was gathered for every market segment to allow for justified conclusions. Yet a clear difference in average utilization is visible between the 'home' segment (consisting of home & garden and home appliances), and the 'consumption' segment (consisting of food/near food and health & beauty). When conducting the sample it was observed that the products in the first two market segments are relatively large in size and are packed in a variety of boxes, whereas the products in the latter segments are generally small and almost always packed in the smallest box available. Shoes & personal lifestyle show a similar pattern in the sample, as most products represented jewelry, watches, and small bags instead of shoes.

Data have indicated that the highest potential of volumetric reduction is attainable in shipments with a relatively low number of items (four items per order or less) and in food/near food, health & beauty, and to a lesser extent in shoes & personal lifestyle.

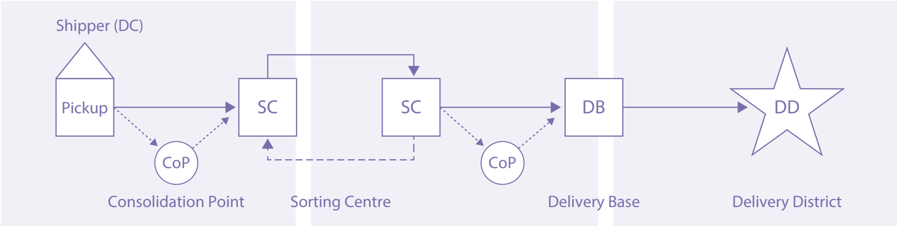
Single-item orders were analyzed in further detail. These orders accounted for 61.1% of shipments. Average utilization here was 23.4%. By using available made-to-measure technology, a parcel based on the dimensions of the product was simulated. In 14 instances, it was not possible to create a suitable parcel because one or multiple dimensions of the product exceeded the maximum available size. The smallest available parcel was chosen when one or multiple product dimensions were less than the minimum parcel size. Utilization, on average, then increased to 40.0% for this batch of single-item orders.

A second data set provided by a made-to-measure packaging provider has indicated that the parcel size of multi-item orders could be reduced by 35% on average. For single-item orders the volume reduction in this data averaged out at merely 3%, with both positive and negative deviations. The volume of the goods in this second data-set however was significantly larger than the goods in the sample discussed in this paper (26.19 dm3 vs. 7.52 dm3 respectively). Available technology might constrain the possible volumetric savings in this case, since it is not yet possible to decrease the minimal packaging dimensions of the machine. There is only a small increase in utilization since the smallest box available is still considerably larger than the packed products.

Analysis has shown that the average volumetric utilization in any case is well below 40%. When excluding dimensional item restrictions preventing 100% utilization, volumetric savings of 20% seem easily achievable. Question remains whether an industry-wide volumetric reduction of 20% would also lead to more efficiency in carrier networks.

Efficiency dynamics in parcel networks

Previous research indicated that the degree of consolidation (*average number of parcels per transport activity*) varies significantly throughout the three transport sections defined initially. Yet this appears to be a significant variable in regards to potential efficiency gains, as less consolidated flows might face different limitations than highly consolidated ones. In last-mile delivery vehicles for instance, timely constraints might turn out to be more significant than the maximum volumetric capacity of the vehicle. Constraining factors as these could lead to decreased or even eliminated efficiency gains in networks, once volumetric efficiency increases.



Parcel Collection		Inter-hub transport		Last-mile distribution	
Volume projection	(o.d.)	Routing	(Alumur & Kara, 2008)	Delivery intervals (Time Slots / Late)	(Baumung et al.,2015)
Collection times	(Gündüz et al., 2015)	Transport intervals	(Baumung et al.,2015)	Delivery district structure (Size / Shape)	(o.d.)
Customer service level	(Baumung et al., 2015)	Annual volume growth	(Alumur & Kara, 2008)	Delivery district density	(o.d.)
Location of origin	(Meisen, 2015)	Location of SCs & DBs	(Baumung et al., 2015)	Fleet composition / Vehicle capacity	(Baumung et al.,2015)
Consolidation at origin	(Meisen, 2015)	Vehicle capacity	(Baumung et al.,2015)	Trip routing	(Baumung et al., 2015)
Fleet composition /Vehicle capacity	(Baumung et al., 2015)	Fleet composition /Vehicle capacity	(Grünert & Sebastian, 2000)	Direct deliveries	(Meisen, 2015)
Trip routing	(Baumung et al., 2015)			Annual volume growth	(Meisen, 2015)
Direct deliveries	(Meisen, 2015)			Drop rate Delivery Modes / FirstTimeRigh	(o.d.)

Figure 5 Essential transport sections of a parcel network.

In order to evaluate potential constraints as these, interviews with two major Dutch parcel carriers with a combined market share of more than 90% have been held in order to discuss and validate the factors found in literature (Figure 5). Findings as a result of these validations will be presented based on the three transport sections defined initially.

Parcel collection

Parcel collection is the first transport section of the three sections that make up a carrier network as introduced earlier. Parcels are collected from different sources (e.g. post offices, business customers, private individuals) and transported to a sorting center. Volumetrically efficient parcels can hypothetically reduce the need in total transport capacity in parcel collection. However a variety in network factors might be relevant for savings to take effect:

Volume projection

Carriers request shippers to provide an estimation on the number of parcels that have to be transported in the future. This projection is used to make a rudimentary planning for parcel collection. Parcel carriers strive for considerable economies of scale and density in parcel collection as the cost price per parcel decreases with an increase of the volume (ACM, 2016a), this can only be done under a projection of resources and transports required. According to carriers, volume projection itself has no operational influence on possible savings attained by volumetric reduction, unless major savings would be achieved in the short run throughout major shippers, which is considered to be rather unlikely.

Collection times

An important determinant for the actual volume loaded at business customers is the collection time (also: cut-off time). Collection times are determined by the carrier in order to be able to fulfil lead-time requirements such as next-day delivery (Gündüz, Hempsch en Sebastian, 2015). Savings due to volumetric reduction may not take effect when the trigger for a collection is the time required to fulfil such a lead-time requirement, and not a capacity limitation (*a full vehicle)*. According to carriers, this is the case for approximately 90% of all collection activities, hence collection times represent a significant constraint in regards to an efficiency increase under identical fleet composition, as in most situations a full utilization, with regard to both weight and volumetrics cannot be achieved.

Customer service level

The service level that the customer demands of a parcel carrier impacts collection times (see above) or forces carriers to employ inefficient routing in a network when vehicles can't be utilized efficiently due to additional time constraints. Examples of these quality requirements include evening deliveries, Sunday deliveries, scheduled deliveries, and same-day delivery (ACM, 2016a). Increased service level and more variability in delivery options will lead to less efficient use of the network and will oppose possible volumetric savings. For simplicity reasons however only standard delivery is considered in this paper, hence the implications in regards to service level influence the collection times discussed previously.

Location of origin

Parcels can be collected from businesses, private addresses, delivery depots & stations, local affiliates, pack-stations and parcel boxes (Meisen, 2015). The location of these sources has an effect on the utilization of the pickup vehicle as it determines the share of time spent driving opposed to dropping (parcels). Multiple sources or long distances between sources limit the volume that can be loaded due to constraints caused by the customer service requirements mentioned above. Yet locations of origin do not influence the potential savings attained by volumetric reduction, as these would remain identical in both scenarios.

Consolidation at origin

Consolidated goods from multiple sources, i.e. multiple customers allow more volume to be collected as time for transportation and handling activities can be reduced, whereas decentralized, fragmented pickups lead to more time required, limiting the volume loaded in a vehicle. An increase of consolidation at the origin will reduce the time constrains caused by quality requirements (vehicle is full after fewer collections) hence according to carriers it will positively influence effects of volumetric reduction in parcel collection. Furthermore the significant growth in parcels shipped leads to an increase in average consolidation as the quantity of shippers does not increase in line.

Fleet composition

To combat poor vehicle utilization due to changes in quantities, parcel carriers have the possibility to deploy smaller or bigger vehicles, thereby decreasing or increasing collection capacity on a particular route (Baumung et al., 2015). According to carriers, this is currently not relevant as there are barely any operational changes in fleet deployment with regard to vehicle type on particular routes (standard vehicles are used within a particular transport route).

Trip routing

The pickup route is based on a predefined, optimized, sequence (Baumung et al., 2015). This process is similar to trip routing in last-mile distribution. For this paper it will be assumed particular routes are a given constraint. This is in line with what carriers state with regards to their planning processes. While certainly trips might change with volumetric efficiency, these changes would be based on factors discussed previously.

Direct deliveries

Meisen (2015) argues that lead times can be shortened and capacity in certain nodes can be relieved with the help of direct deliveries from pickup to delivery base or even district. The biggest disadvantage however is that outgoing parcel quantities are rather small and do not fully utilize the capacity of transport vehicles available. Volumetric reduction of parcel size will lower utilization even further and will lead to no efficiency gains in these deliveries. At the same time direct deliveries are to be seen as an exceptional mean, altering standard network flows. This means they can be regarded as a temporary solution for urgent problems rather than a part of a standard parcel network.

Annual volume growth

Between 2012-2016 a growth trend could be observed with regard to parcels shipped in the Netherlands (about 8% annually). Average revenues for domestic parcel deliveries decreased with 6.7% in the same period. Although parcel carriers state that considerable economies of scale and density can be realized in parcel transport and that cost price per parcel can be reduced with an increase of the volume, this is not yet reflected in their average revenues (ACM, 2016a). Savings due to volumetric reduction of parcel size increase economies of scale and density allowing cost per parcel to be reduced and may lead to an increase in average revenues. It has also been observed that this growth influences other factors, such as consolidation at origin.

Of all factors discussed above, collection time was the most significant for the parcel carriers in question. They state that savings due to volumetric reduction in parcel collection are only attainable once time constraints have been ensured. Therefore they conclude that under 20% volumetric reduction in average parcel size, 1-5% efficiency gains can be achieved, strongly depending on the shipper portfolio. While for large shippers significantly higher savings can be achieved, collection at smaller parties will not benefit from improved volumetrics at all.

Inter-hub-transport

Inter-Hub transports represent the transport activities between all larger nodes of a parcel network. This may involve both SCs and DBs. Both types of facilities represent the main nodes for re-routing parcels nationwide, almost all shipments pass them at some point. At the same time, few redundant facilities of this type exist as they are positioned on a regional or national basis. Therefore, inter-hub transport represents the most consolidated transport section in a parcel network (Graf, 2000). This leads to high expectations in regards to efficiency gains by means of volumetric reduction, as a singular transport can achieve maximum capacity much quicker. The following factors have been discussed for inter-hub transport:

Routing

Almost all of today's parcel networks operate in accordance with Graf's (2000) direct-traffic-network-concept (*Direktverkehrsnetzwerke*), allowing for the application of direct shipments between identical network nodes, for instance SCs. While theoretically a trip (or route) can contain transports from/to more than one SC, this is often not done due to timely restrictions and increased mileage according to carriers.

Transport intervals

Baumung et al. (2015) describe the relation between parcels requiring transport by means of a certain network, and the average waiting time between scheduled transport activities, for instance between two SCs. The more critical (delivery) lead times become, the lower the demand for transport during one particular time slot. In same-day services, inter-hub waiting time can become as short as 60 minutes (o.d.). Parcels missing these narrow time slots will ultimately delay to the next transport scheduled. Express deliveries are therefore expected to have a negative impact on the efficiency of efficient inter-hub transportation, unless they are transported in combination with non-urgent shipments under higher urgency. While this neglects that adjacent transports such as collection and delivery are scheduled, hence arrive on time, it still leads to a lower total volume transported during one particular transport due to more vehicles being deployed. According to participating carriers, the ultimate effect of these intervals is negligible, as demand per route exceeds lead-time restrictions due to the tremendous demand growth in recent years, particularly for standard deliveries. Here, the average utilization of inter-hub transports approximates 100% for large networks, and transports are triggered by volumetrically full vehicles rather than (timely) delivery restrictions.

Annual volume growth

As discussed for transport intervals, the total number of parcels forwarded in a network on a structural basis counteracts the effects resulting from shortened transport intervals. With an annual growth of about 8-12% in parcel units forwarded (ACM, 2016a), there is a strongly positive relation between network efficiency when creating full inter-hub truckloads under identical or improved timely restrictions. ACM (2016b) even highlights these positive developments explicitly stating that larger volumes and automation have increased the efficiency of parcel forwarding.

Location of SCs & DBs

Both quantity and positioning of SCs / DBs represent important factors with regard to the volumes injected into a SC. Geographical surroundings may or may not generate sufficient flows due to, for instance, population density. These inter-hub routes may not be benefiting from reducing total volume even further, as no or little reduction in vehicles can be achieved when volumetric demand during a transport is below one vehicle. This would affect the efficiency of inter-hub transports. As most parcel carriers operate with legacy infrastructure, however under strong growth in demand, the consequences of this factor do not seem to create substantial differences amongst more or less efficiently created parcels, certainly not on inter-hub transport efficiency. According to the carriers in question, the annual volume growth counteracts this factor strongly as inter-hub routes are already fully utilized.

Vehicle capacity

Major parcel networks utilize large capacity transport modes *(trucks)* in inter-hub forwarding. These transport modes are ultimately limited in two ways: Volumetrically *(space)* and in regards to maximum payload *(weight)*. Carrier representatives claim that the limitation applicable, especially for these truckloads, is of volumetric nature as payload limitations aren't approximated in their inter-hub transports. While they *do* admit that punctual lead-times are the primary objective, it has already been concluded that these are not a real inhibitor of capacity utilization. Therefore, an overall reduction in inter-hub rides is attainable by means of lowering average volume per parcel under current vehicle capacity constraints.

Fleet composition
A variety in transport vehicles that can be deployed on a transport route to allow for adapting to demand fluctuations in a network. Smaller vehicles in times of low demand lower emissions and fuel consumption, hence allow for financial savings. Yet this is only feasible to a limited extent as alternative vehicles involve financial investments, and reduce usage of all other assets, as they need to be kept available. According to carriers, this potential capacity flexibility is not used in their inter-hub processes. Standard (*fixed*) vehicles are used in inter-hub transport.

When collecting information on the factors above, carriers have explicitly stated that there is currently no network variable or factor directly counteracting efficiency savings created by means of volumetrically efficient packaging in inter-hub transport. It has even been said that volumetric reductions under identical total weight would lead to "*1:1 savings in this transport section*". Hence it can be concluded that 20% volumetric reduction would lead to approximately 20% reduction in inter-hub rides and therefore also kilometers for the networks in question.

Last-mile distribution

Last-mile distribution, in this case solely representing transport processes from DB to destination address, represents the most fragmented of the three transport sections (Baumung et al., 2015). According to literature, quite a number of potential factors in this section bear the potential of limiting ultimate performance with regards to volumetric weight. Therefore the following section will outline the conclusions drawn on their relevance in terms of volumetric savings as drawn by parcel carriers.

Delivery intervals
This factor has been said to be negligible with regard to inter-hub transports as all transports are fully utilized, yet in the last mile they are said to represent an essential part of the problem. Extended service propositions introduced in recent years such as time frame- and late delivery have led to a significant increase in transport intervals. According to participating carriers, delivery vehicles are almost never fully utilized. When introducing additional delivery time slots, average volumetric utilization decreases further.

Delivery district structure

A delivery district is a geographical delivery area determined based upon the demand in that certain region, for instance a city district. The geographical surface of these districts decreases once demand in a certain area rises, as there is a restriction in parcels that can be delivered by means of one vehicle covering a district. These geographic reallocations have taken place in recent years, however they seem to be connected to structural network changes rather than a steady demand increase. Hence a constant decline in the average distance of a tour is visible, yet this is not expected to be of crucial significance according to carriers.

Delivery district density

Less deliveries are executed in rural areas compared to dense, urban areas due to larger transport distances between individual deliveries. Yet areas that have faced a decrease in population density have also faced developments as demand growth with regard to parcel deliveries. This is why district density does not pose a risk to increase efficiency by means of reduced volumetric dimensions. For areas with high population density, other factors are currently limiting the amount of deliveries per delivery vehicle.

Fleet composition

Type and composition of a carrier fleet however appears to be a factor for some for the carriers questioned. One carrier in particular observes a significant difference in regards to their own fleet in comparison to their competition. This carrier states that the own delivery fleet, while satisfactory in general, has to cope with volumetric restrictions. For about 3-5% of their vehicles, volumetric restrictions appear to limit the number of shipments transported in the last mile. In these few cases however no substantial difference to usual delivery performance can be observed. Hence the volumetric limitations in the fleet of the particular carrier in question are *in these cases* close to their current drop-rate as a constraint. A significant exception, according to carriers, are alternative and often more ecological fleet solutions, for instance cargo bikes. These delivery modes bear significant volumetric restrictions and would strongly benefit from a higher volumetric utilization of parcels. These modes however represent a niche in the total carrier fleet and are therefore not regarded as relevant. One carrier on the other hand stated that current volumetric limitations represent the main obstacle to the large-scale introduction of modalities such as cargo bikes.

Trip routing

Trip characteristics as mentioned by Baumung et al. (2015) will be regarded as an input variable influencing delivery district structure, hence they do not directly relate to the consequences for volumetric efficiency.

Direct deliveries

When a consignee receives large amounts of parcels (often in B2B networks), using a dedicated delivery vehicle makes sense. Yet only for a negligible minority of all trips the demand per destination is sufficient to make direct deliveries to a consignee. With the volumetric constraints in fleet composition discussed earlier, the requirement of a full vehicle load would be achieved later under a reduced average parcel size, hence direct deliveries would decrease. This however is not expected to have a strongly negative influence on the efficiency gains as it is relevant for an absolute minority of all trips made. The 3-5% restriction discussed in Fleet composition is likely to correlate with these direct deliveries to fewer consignees.

Annual volume growth

According to carriers, the increase in parcels shipped is influencing (volumetric) delivery vehicle utilization positively, yet not to an extent where volumetric limitations are the constraining factor for delivery routes. This constraint is currently caused by an entirely different factor.

Drop rate

The so called drop rate is a mixture of different process aspects discussed previously: (1) The average distance between stops, (2) the consolidation degree per stop (number of parcels dropped per stop), and (3) the average time required per delivery (/per parcel). The drop rate specifies how many parcels can be delivered by means of a delivery vehicle within a particular timeframe, for instance one hour.

Except for the average distance between stops, no significant changes have been observed in recent years with regard to drop rates. The absolute majority of parcels is delivered as single-shipment, using attended home delivery as the main delivery mode. The time intensive nature of the three aspects combined leads to time (as given by the duration of a shift) being the most crucial limitation in last mile delivery. Vehicles cannot be filled to their maximum capacity as the drops required under full capacity could not be made within a shift. Hence the drop rate is to be determined as the most significant of all factors in this transport section. In literature, carriers claim that drop rate has improved when increasing the usage of alternative delivery modes like parcel lockers or collection points (McCauley, 2017). This is most likely due to the higher consolidation of deliveries to these destinations. These findings however could not be validated for the Dutch carriers in question, as they have not initiated significant (large scale) changes in delivery modes in recent years.

In conclusion it can be said that amongst the factors discussed, the drop rate of delivery vehicles represents the main inhibitor with regards volumetric savings in last-mile distribution. Particularly the consolidation of drops and the time required per drop seem to be an issue with regard to delivery efficiency. While, according to carriers, a minority of vehicles is limited by means of volumetric aspects rather than drop rate, this does not hold true for the absolute majority of trips made. Carriers therefore estimate the savings attainable by means of 20% volumetric reduction to be in a range between 0-1% reduction in kilometers for last-mile distribution under current drop-rate constraints.

Combined effect of volumetric reduction

Based on previous findings in literature and interviews with parcel carriers, it can be concluded that a number of factors in the network sections discussed can make or break the volumetric efficiency gains attainable. Certainly not all factors discussed are relevant in the current situation, however this might change under different circumstances, such as a change in fleet or annual market growth. The following table summarizes to which extent a factor enables (+) or hinders (-) efficiency gains under volumetric reduction.

Table 1 Efficiency dynamics in combination with volumetric reduction of average parcel size.

Parcel collection		Inter-hub transport		Last-mile distribution	
Volume projection	O	Routing	O	Delivery intervals	-
Collection times	--	Transport intervals	O	Delivery district structure	+
Customer service level	-	Annual volume growth	++	Delivery district density	O
Location of origin	O	SC/DB location	O	Fleet composition	+
Consolidation at origin	++	Vehicle capacity	+	Trip routing	O
Fleet composition	+	Fleet composition	O	Direct deliveries	+
Trip routing	O			Annual volume growth	++
Direct deliveries	-			Drop rate	---
Annual volume growth	+				

Conclusion and discussion

A volumetric analysis of more than 130 parcels has confirmed that 20% volumetric reduction in parcel size seem easily achievable with the help of made-to-measure packaging technology, opposed to using 14 standard box sizes. The subsequent investigation on the effects of this volumetric reduction on carrier networks has shown that there are quite substantial differences between the parts of a network with regard to efficiency gains attainable. A volumetric parcel size reduction of 20% will lead to an equal (20%) reduction in inter-hub transports & kilometers, 1-5% reduction in kilometers for parcel collection and virtually no reduction (0-1%) in last-mile distribution. Hence 1:1 savings are attainable in inter-hub transportation, ~6:1 in parcel collection, and none in last mile delivery.

Previously it has been theorized that an increase in volumetric efficiency (hence a reduction in size) may positively influence the congestion of carrier networks as it bears the potential to reduce transport activities under identical demand (goods shipped) and lead-times. This has shown not to be true for last-mile distribution. Improvements however could be found particularly for inter-hub transports, and to a certain extent also for parcel collection. Significantly less transport activities would be the result of the volumetric reduction discussed, hence congestion in these sections is less likely and could, to a certain extent antagonize the immense growth in parcel networks. Workforce and vehicles formerly allocated to these processes could in some cases even be used for last-mile distribution if required.

Wasner and Zäpfel (2004) stated that approximately 25% of all costs in a parcel network originate from inter-hub transports (depot operating costs are excluded from this percentage). Another 20-25% is allocated to parcel collection. When linking these figures to the savings attainable by means of 20% volumetric reduction, 6-7% in total cost reduction seem achievable by means of this technique. As not all shippers will be able to create volumetrically optimized shipments due to the large investments required, these figures may serve as an indication for tariff discounts given to shippers who engage in volumetric optimization of parcels. The precise effects on carrier networks substantiated by means of network simulation will be a topic of future research.

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