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Cost Modelling and Simulation of Last-mile Characteristics in an Innovative B2C Supply Chain Environment with Implications on Urban Areas and Cities

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Abstract

The last mile in a B2C environment is currently regarded as one of the more expensive, least efficient and most polluting sections of the entire logistics chain. Taking these “last mile problems” into account, the authors developed a last-mile typology and an instrument to simulate the total last-mile costs whereby specific last-mile characteristics are used as independent variables.

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1. Introduction

This article is the closing part of a broader research project about B2C last mile logistics. The focus in the previous phase of the research was on a detailed qualitative analysis of a last-mile typology on the basis of desk research. During this first phase (Gevaers, Van de Voorde & Vanelslander, 2009 & 2011) a list of cost drivers (“characteristics”) affecting the last mile was drawn up on the basis of desk and field research. The present phase consists of the development of a last mile costs model that is able to simulate **the B2C last mile costs per unit**

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delivered. For the development of this cost model, data from both academic literature and interviews with experts was used. First of all, a brief summary of the results from the former research parts will be presented in the following paragraphs. Hereafter, the methodology and the results of some scenario simulations using the cost calculation model will be described and analyzed. The main research questions to be answered in this article are: “What are the potential cost effects caused by B2C last mile cost characteristics (cost drivers) in urban areas?” and “How can these costs per delivered unit be simulated?” In other words, the objective of this paper/research is to “come to an understanding of the cost effects caused by changes (mainly economic ones, but also environmental ones) within characteristics (cost drivers) of last-mile logistics in urban areas”.

1.1. Findings former research parts concerning B2C last mile logistics

First of all, we wish to define what is considered as B2C last mile logistics within our research as, “the final leg in a business-to-consumer delivery service whereby the consignment is delivered to the recipient, either at the recipient’s home or at a collection point” (Gevaers, Van de Voorde & Vanelander, 2009).

Table 1 summarizes the main findings from the former research parts. In Gevaers, Van de Voorde & Vanelander (2009 & 2011), the authors revealed that the nature of the last mile can be determined largely by five fundamental aspects (cfr. “generalized characteristics”): the level of consumer service, security and delivery type, the geographical area, the degree of market penetration and density, the vehicle fleet and technology employed, and the environmental impact. Each of these elements was elucidated and analyzed in detail. Subsequently, these five generalized characteristics consist of several related sub-characteristics.

Table 1. Efficiency characteristics and sub-characteristics within the B2C last mile (Source: Gevaers, Van de Voorde & Vanelander, 2009 & 2011)

LEVEL OF CONSUMER SERVICE	SECURITY & TYPE OF DELIVERY	GEOGRAPHICAL AREA & MARKET DENSITY / PENETRATION	FLEET & TECHNOLOGY	THE ENVIRONMENT
Time windows	Home delivery with signature (attended) vs. non-attended	Density	Type of delivery vehicles	Packaging
Lead time	Collection points	Pooling of goods	ICT	Trade-off between time factors and environmental impact
Frequency				
Returns of goods (reverse logistics)				

A substantial last-mile issue in home deliveries occurs if a signature for reception is required. If no specific window of delivery has been arranged, the failure rate due to, ‘customer not at home’ will inevitably be high. Consequently, the parcel may have to be presented two or three times before it is successfully delivered. On the other hand, a pre-arranged delivery window will inevitably compromise routing efficiency. After all, limited delivery windows imply that a courier needs to cover more miles for the same number of deliveries. A second frequently encountered problem is lack of critical mass in a given region, due to an inadequate market density or penetration. If, by consequence, a courier needs to travel over 30 miles in order to deliver a single parcel, efficiency will be strongly reduced and cost greatly increased. Furthermore, consumers are becoming increasingly aware of the environmental impact of logistics and transport choices. More and more often, they demand from logistics providers that they should strive for a constant reduction of their carbon emissions footprint. Yet, more often than not, consumers are not prepared to either pay more or wait longer for their goods in return for a greener service.

The following sections will focus in depth on the methodology used to come to a B2C last mile cost simulation tool. Hereafter, some potential/possible urban last mile logistics scenarios will be simulated with this modelling tool.

2. Methodology

2.1. Definition and understanding of “last mile costs”

It should be emphasised that “B2C last mile costs” are to be understood as the total last-mile logistics costs per unit delivered. In other words, it refers to the “total cost of ownership” of the last mile. The constituting costs are not always passed on (in their entirety) to the shipper or to the customer/consumer. In this article, these costs are calculated from the moment the parcel/product is shipped (from the shippers’ last DC or the logistics service provider’s last DC) till the moment it is delivered at the consumer’s home or at a collection point. If the parcel/product is sent back by the customer (returned), then full account is taken of any additional costs up to the moment when the item is returned to inventory, as if it had never been shipped. The starting point is invariably that of an internal standard delivery cost.

2.2. Model building

Due to a lack of (confidential) cost data from the sector (due to the very competitive market, the players of the last-mile market do not provide cost data, due to confidentiality reasons), a cluster analysis or factor¹ analysis was not possible². Nevertheless, with all the obtained knowledge and data from literature and interviews, it was possible to build up a logistics last-mile cost function based on a general time and distance transport cost function from Blauwens, De Baere & Van de Voorde (2010).

The standard lay-out of this function is: $TC = T \times t + D \times d + Z$ (1)

where:

- TC stands for total transportation cost
- T stands for the duration/time of the transport
- t stands for the time/hour coefficient
- D stands for the distance driven/travel for the transport
- d stands for the distance coefficient
- Z stand for extra costs not related to distance and/or time

The time coefficient (t) needs to be multiplied by the real time driven/worked (T) for obtaining the total time costs of the total transport costs. The distance coefficient (d) needs to be multiplied by the total amount of driven kilometres (D) for obtaining the total distance costs of the total transport costs. The sum of these two costs and some possible extra costs which are not time and distance based (= Z) make the total transport costs (= TC). The t-coefficient and d-coefficient for the year 2011 can be found in Table 2.

¹ For executing a cluster or a factor analysis trustful cost data is needed from a minimum of 30-35 last-mile companies. If such an analysis is executed using data from less than 30-35, than there might rise a validation problem with the results.

² Not enough cost data to obtain significance using factor or cluster analysis.

Table 2. Average costs for road haulage (2011) (Source: Own adaptation on the basis of Blauwens, et al (2010))

Payload	Time coefficient (t)	Distance coefficient (d)
Delivery van 0.5 ton	22.26	0.16
Lorry 5 tons	23.70	0.23
Lorry 8 tons	24.88	0.27
Lorry 20 tons	28.52	0.33
Tractor + semi-trailer 28 tons	29.74	0.37

2.3. Adaptation of the transportation cost function to the last-mile cost function

First of all an overview of the used independent variables (sub-characteristics) with their symbols can be found in Table 3

Table 3: Used symbols (Source: Own composition)

STOP	Average number of stops (addresses) per delivery route per driver per day	cp	Collection points coefficient
Q	Average quantity of products in the parcel	ad	Area density coefficient
w	Time window coefficient	p	Pooling ³ of parcels coefficient
r	Reverse logistics coefficient	v	Type of vehicles/vans coefficient
lc	Logistics handling cost coefficient	lct1/ lct2	ICT coefficients
ht	Average handling time in the reverse leg of a chain	pac	Packaging coefficient
ip	Manned versus unmanned (in person) delivery coefficient	SHF	Extra special handling fee that can be added (example: insurance)

When looking to the aforementioned symbols, it is correct that not all the B2C last mile sub-characteristics can be found within this list. This is due to the fact that some sub-characteristics are a combination of cost effects of other sub-characteristics. This will also be analyzed and discussed in the following paragraphs.

We start from the standard function (1): $TC = T \times t + D \times d + Z$

Due to the fact that the last-mile part of the supply chain is executed in most cases by vans or small trucks⁴, we propose to use the coefficients of van (small lorry 5 tons) transport:

where:

$$t = 23.70 \quad \text{[assumption 1]}$$

and

$$d = 0.23 \quad \text{[assumption 2]}$$

³ Pooling means that parcels are brought together on specific locations so that parcels of different shippers can be delivered together in one route instead of each shipper or last-mile provider executing a similar route but with a lower loading degree.

⁴ During interviews with experts the rate of 70% to 80% was mentioned many times as an estimate for the share of van transport in the last-mile. Bikes and small trucks are the other 20% to 30%.

This makes:

$$TC = T \times \underline{23,70} + D \times \underline{0,23} \quad (2)$$

In the following paragraphs we will extend step-by-step the time and distance-based transport function to a B2C last mile cost simulation function. We will mainly focus on the sub-characteristics that can have major impacts in urban environments.

2.4. Model development

2.4.1. Stop coefficient [STOP]

It should be intuitively clear that the average number of stops (or drops) than can be executed during a route reduces the TC by the number of stops.

$$\text{So this gives an extension in the function as: } \frac{TC}{STOP} \quad (3)$$

2.4.2. Unit coefficient [Q]

The aim is to build a B2C last mile costs model that is able to simulate the costs per unit delivered. As a result, the average number of units per parcel reduces the TC by the number unites per parcel.

$$\text{So this gives an extension in the function as: } \frac{TC}{Q} \quad (4)$$

2.4.3. Time window coefficient [w]

As already analysed in the former last-mile parts, narrowing time windows implies ping pong effect in the router patterns, which also implies that less parcels can be delivered within a specific time (for example the working day of a driver). Therefore, the average number of deliveries per driver per day per route will decrease if consumer time windows narrow down. Hence, the time window coefficient (w) is a coefficient that gives information about the decreasing number of delivered parcels due to efficiency constraints. The time window coefficient is a coefficient that decreases the number of STOPS linear per route.

$$\text{So this gives an extension in the function as: } \frac{STOP}{w} \quad (5)$$

w can have the following values:

- If no time windows: $w = 1$
- The narrower time windows becomes, the more w increases.

In Table 4, an overview of the most common time windows can be found (Boyer, Prud'homme & Chung, 2009). The coefficients are based on the findings from Boyer, Prud'homme & Chung (2009) that can be used as base values for deliveries with time windows⁵.

Table 4: Time window coefficients (Source: Own calculations based on Boyer, Prud'homme & Chung, 2009)

Window length	Assumed coefficient
1 hour	2.1
2 hour	1.8
3 hour	1.6
4 hours – half a workday	1.3
No time window – full day	1

⁵ For specific in detail descriptions, the authors wish to refer to the book of the referenced authors

2.4.4. Reverse Logistics Coefficient [*r*, *lc*, & *ht*]

This “*r*” coefficient indicates the cost effects if a parcel is returned to the shipper’s or the logistics service provider’s DC. In this function we assume on the basis of expert interviews that the cost of the total last-mile flows (so from DC to consumer and back) implies that for obtaining a correct cost indication, the standard last-mile transportation cost needs to be multiplied by two (outbound and reverse inbound) and that one has to take into account the extra handling costs of a specific handling time for checking the returned goods and putting them back in inventory. It can be said that the *r* coefficient is a dummy variable: its value is 0 or 1.

$$\text{So this gives an extension in the function: Cost per parcel/unit } x(1 + r) + \frac{(r \times lc \times ht)}{Q} \quad (6)$$

In this function, the first part $(1 + r)$ refers to the outbound and inbound transport cost. If there is no reverse leg, $r = 0$, so only the outbound cost is taken into account. If there is a reverse leg, $r = 1$. As a result will the outbound and inbound taken into account in the calculation. The second part $(r \times lc \times ht)$ refers to the cost related to the checking of the parcels and putting the goods back in inventory. This needs to be divided by the number of units to calculate the correct cost per unit/product. If there is no reverse leg, $r = 0$, this part of the calculation will be $(0 \times lc \times ht)$ so that this whole part will be 0.

2.4.5. Manned versus unmanned coefficient [*ip*]

The “*ip*” coefficient is based on the earlier mentioned “first time hit rate”⁶. A low first time hit rate implies that the real number of effective (successful) stops will decrease compared to the average number of stops. So therefore, the average number of stops (STOP) needs to be multiplied by the percentage of first time hit rate (*ip*). In the functions this means that the STOP coefficient/variable needs to be multiplied by the first time hit rate percentage (*ip*). The *ip* coefficient is a value between 0 (FTHR = 0%) and 1 (FTHR = 100%). The growing number of parcel drops using collection box kiosk (for example the Deutsche Post – DHL Packstationen) implies a higher FTHR than home deliveries. (Weltevreden, 2008).

$$\text{So this gives an extension in the function as: STOP} \times ip. \quad (7)$$

2.4.6. Collection points coefficient [*cp*]

When using collection points, this means that the average number of parcels delivered per drop increases and a second possibility is that the first time hit rate increases. Therefore, the number of drops needs to be multiplied by the effect of using collection points. There might be a possible effect on the first time hit rate, but in the further simulation, we assume that this is not the case and is incorporated in the *cp* coefficient. This *cp* coefficient should be based on logistics data from the shipper or the logistics company. One important remark is that when one is executing only collection point stops/drops, the *ip* coefficient should be set on value 1. Example: If one only executes collection point drops and every collection point drop contains 5 parcels, $cp = 5$ ⁷.

$$\text{So this gives an extension in the function as: STOP} \times cp. \quad (8)$$

Table 5: Collection point coefficient (Source: Own composition)

Coefficient	Symbol	Analysis
Collection point	<i>cp</i>	If no => <i>cp</i> = 1 , if yes => <i>cp</i> >= 1

2.4.7. Density and area coefficient [*ad*]

The density (and market penetration) of delivery areas/regions can have significant impacts on the efficiency.

⁶ Further on referred to as FTHR.

⁷ There is a volume maximum on the number of parcels that can be transported in one van. This is discussed in the simulation part of this article.

The density can increase/decrease the real travel distance compared to the “average distance travelled⁸” for executing the “average number of stops” so this implies that it can increase/decrease the number of stops compared to the “average number of stops”. Hence, the coefficient ad^9 gives the relation between the effect on the increasing/decreasing number of stops in a certain region when the average amount of driven kilometres stays the same.

In the cost functions this gives the following additions: $STOP \times ad$. (9)

On the basis of Boyer, Prud'homme & Chung (2009), we assume the following values for coefficient ad .

Table 6. Assumed coefficients per density class (Source: Own composition on the basis of Boyer, Prud'homme & Chung, 2009)

No of inhabitants per square km	Assumption coefficient ad
0-50	0.5
51-200	0.93
333 (Density/km in Belgium)	1 (Index)
201-400	1.09
401-600	1.24
601-800	1.31
801-1000	1.35
1001-1200	1.38
1201-1500	1.39
> 1500	1.41

This table implies indeed that the density of an area is positively correlated with the number of possible stops a driver can execute in a specific time frame. If a consignee lives for example in an area with a density of around 900 inhabitants ($ad = 1.35$), the number of possible stops will increase by approximately 35% taking the same amount of kilometres into account.

2.4.8. Pooling coefficient $[p]$

The “ p ” coefficient gives an indication on the possible cluster effect during the deliveries. In other words, if for example logistics companies would work together in a specific region, they might be able to cluster/pool goods and execute a larger amount of stops/drops compared to the average amount of stops when keeping the driven kilometres per daytime unchanged (*ceteris paribus*). Also longer lead times can have impacts on the “ p ” coefficient. A longer lead time can imply for example that two shippers or logistics companies that need to deliver something in a specific area can pool these two deliveries in one route. If at least one of these two deliveries has a short lead time and the other parcel is not ready for being shipped, the possibility of pooling will not be there. This “ p ” coefficient should be based on logistics data from the shipper or the logistical company.

So this gives an extension in the function as: $STOP \times p$. (10)

2.4.9. Vehicle type coefficient $[v]$

Also the type of rolling stock/vehicles can have impacts on the last-mile costs. Due to the fact that the type of vehicle/van is directly related to the cost of driving, the “ v ” coefficient can increase/decrease the distance cost

⁸ Starting from a reference scenario (see further on in the text)

⁹ If the other would not be set on 1, one might count the cost effect twice.

coefficient compared to the average distance cost coefficient “d”. The specific “v” coefficient is a percentage of the possible increase/decrease of the average “d”. This “v” coefficient should be based on data from the shipper, the logistical company, a transport federation or from a truck/car manufacturer. This coefficient should be interpreted as is described in Table 7.

So this gives an extension in the function as: $d \times v$ or $0,13 \times v$ (11)

Table 7. Vehicle type coefficients (Source: Own composition)

Vehicle type	Relation
If $v = 100\%$	The vehicle type has the same “d” coefficient than assumed (0,23 ¹⁰)
If $v < 100\%$	The vehicle type has a lower than market-average operating cost
If $v > 100\%$	The vehicle type has a higher than market-average operating cost

2.4.10. ICT coefficient [ict]

The “ict1” coefficients gives the relation between the effect on the increasing/decreasing number of kilometres/miles one has to drive to execute in a certain region the average amount of stops. The “ict2” coefficients gives the relation between the effect on the increasing/decreasing time needed for executing in a certain region the average amount of stops. Depending on the data logistical companies or shippers have, they need to select one of ict1 or ict2 and set the other coefficient on 1¹¹.

So this gives an extension in the function as: $D \times ict1$ or $T \times ict2$ (12)

Table 8: ict coefficients (Source: Own composition)

Coefficient	Symbol	Analysis
ICT coefficient on distance	ict1	If ict1 is not 1 \Rightarrow ict2 = 1
ICT coefficient on time	ict2	If ict2 is not 1 \Rightarrow ict1 = 1

2.4.11. Packaging coefficient [pac]

Packaging can have significant impacts on the efficiency of the number of stops and/or the filling of the van/vehicle. By using optimal packaging, one can save on last-mile cost due to volume parameters and delivery/stop parameters.

So this gives an extension in the function as: $STOP \times pac$ (13)

2.4.12. Consumer’s environmental awareness (trade-off between time & environment)

This characteristic is a compilation of all the influencing coefficients which are related to service levels and density levels. If consumers or consignees would be aware of the environmental impacts of their delivery choices, some of these consumers might select for a more environmental method of delivery, for example the use of collection points of not opting for short lead times, etc. If this would be the case, this means that changes in consumer delivery choices will impact most significantly on the w, ad and p coefficients¹².

2.5. Integration of the B2C last mile coefficients into the total cost [TC] function

All these equations ([assumptions 1 & 2] and extensions (1) to (13)) make:

¹⁰ See further on.

¹¹ If the other would not be set on 1, one might count the cost effect twice.

¹² In other words: the sub-characteristics related to time and density.

Last mile cost per unit shipped = (14)

$$\frac{(T \times \text{ict2}) \times 23.70 + (D \times \text{ict1}) \times (0.23 \times v)}{[(\frac{\text{STOP}}{w} \times (\text{ip} + b) \times \text{ad} \times \text{cp} \times Q \times p \times \text{pac})]} \times (1 + r) + \frac{(r \times \text{lc} \times \text{ht})}{Q} + \frac{\text{SHF}}{Q} \times (1 + r)$$

In the following paragraphs, we list some potential urban logistics scenarios within a B2C last mile environment and we will start with the introduction of a reference scenario, for being able to compare costs and cost effects with this “*reference last mile cost*”.

3. Scenario Simulations

Important to underline is that for some sub-characteristics we will assume specific coefficients based on desk and field research. Nevertheless, if in some specific cases company or route related coefficients would diverge from these coefficients for a standard/reference cost, then these can be adapted without any problem in this function.

3.1. List of coefficients for the standard scenario

3.1.1. Assumed coefficients based on expert interviews and academic literature (reference scenario)

The standard (reference) B2C last mile cost per unit shipped is defined as, “*The cost to execute a delivery of a parcel at-home within Belgium whereby no time windows or lead times were agreed, a signature is needed and the delivery address is located in a region that is served by a standard route of the shipper or logistics service provider concerned, and assuming that the goods are not returned. The packaging used is assumed to be standard packaging.*”

Based on experts’ interviews, we assume that an average route (1 day) is about 200km long, that a driver can execute on average 70 stops per route and that this takes 7.5 working hours. Furthermore, it is assumed that on average a parcel is filled with 1.1 products/units and that the average FTHR percentage is 75%. Concerning returning procedures, we assume that on average the checking procedure and putting products back in inventory takes 20min and that on average the wage of blue collar logistics workers is 15 EUR per hour. The average population density of Belgium is 333 inhabitants per km². This makes:

- STOP = 70¹³
- D = 200km
- T = 7.5 hours
- ht = 0.33 hours
- lc = 15 EUR
- Q = 1.1
- ip = 75%
- ad = 1 (→ Index value for ad-coefficient)

There are two main assumptions worth mentioning:

- *When not mentioned in another way, we assume that when the coefficient(s) (of sub-characteristics change), the average speed of a vehicle on a route stays the same. If this is changed in a specific scenario, it will be mentioned in that scenario.*

¹³ One interviewee made the statement that one average a “good driver makes every 5 to 8 minutes a stop/drop”. (Source: Confidential)

- It is assumed that only B2C deliveries are executed. A B2B delivery should be interpreted as a B2C delivery (standard scenario) with a higher first time hit rate¹⁴ and on average more units per parcel.

3.2. Scenario list

Table 9 provides an overview of the selected possible scenarios that will be simulated further on in the text. Many more simulations can be done using the obtained cost function, but the number and the combinations of some of these scenarios is based on findings from academic literature and results from the expert interviews with a focus on (potential) problems occurring in urban areas.

Table 9: Scenario overview (Source: Own composition)

	DESCRIPTION
Scenario 0	Base scenario for B2C last-mile deliveries
Scenario 1	A scenario whereby a last-mile company is evaluating which areas they should (not) serve (deliver). In other words, what can be learned from delivery costs in cities versus rural areas?
Scenario 2	A scenario whereby a last-mile company is evaluating if they should offer time window deliveries. In other words, what can be learned from delivery costs when offering time windows?
Scenario 3	A company that tries for example to convince customers to choose for a delivery at the working location of signature needed deliveries for increasing the FTHR.
Scenario 4	Only offering collection point deliveries
Scenario 5	Executing last-mile deliveries using cargo bikes instead of van/trucks

3.3. Scenario simulations

3.3.1. Scenario 0: Base scenario – reference cost

In this scenario the calculation will be made of what we refer to as “the standard delivery cost”. This base scenario is the combination of what was mentioned as an “average B2C delivery in Belgium” by the interviewed experts.

The simulation of the base scenario delivery cost is **3.87 EUR**. In other words, the average B2C last mile delivery cost (reference cost) is 3.87 EUR. This is in line with findings from independent interviewed experts (for example Hassler, 2011).

3.3.2. Scenario 1: what can be learned from delivery costs in cities versus rural areas?

An e-commerce company or last-mile service provider can choose to focus last-mile services on specific densely populated areas with a high market penetration to deal with inefficiencies or to expand and deliver to all regions in a country (or region). Hence, some simulations will be executed by changing the ad-coefficient. The idea behind this simulation is that if the density is increasing, a driver can execute more stops in a fixed assumed amount of kilometres (=200km) or can execute the same assumed amount of stops (=70) at a reduced number of kilometres.

It was possible to determine the ad coefficients related to the density of an area out of academic literature. (Boyer, Prud’homme & Chung, 2009) Therefore, the simulation with density coefficients will be calculated by using the ad (fixed number of kilometres) coefficient.

¹⁴ The *first time hit rate* is the percentage of how many first delivery attempts to a consignee are on average successful. In B2C delivery rounds this percentage is significant lower than in B2B delivery rounds due to the fact that most deliveries (B2C as well as B2B) are executed during traditional working hours.

Table 10: Cost effects of density (Source: Own calculations)

Density/km ²	Last mile costs/unit	Density/km ²	Last mile costs/unit
0 – 50	€ 7.75	601 – 800	€ 2.96
51 – 200	€ 4.17	801 – 1000	€ 2.87
201–333 (Belgium)	€ 3.87	1001 – 1200	€ 2.81
334 – 400	€ 3.55	1201 – 1500	€ 2.79
401 – 600	€ 3.12	> 1500	€ 2.75

The simulation results show that delivery costs in more densely populated areas can be considerably lower than for deliveries in very rural areas. Delivery costs can almost **triple** (7.75 EUR versus 2.75 EUR) due to the density factor.

3.3.3. Scenario 2: Cost implications of offering time window deliveries in urban areas versus less populated areas

If a B2C company wants to offer time window options for better customer service satisfaction, one has to take into account the possible cost effects of such a decision. Sometimes these decisions are made by other departments than the logistics department (for example by the customers' department).

Table 11: Cost effects of density¹⁵ with narrow windows (Source: Own calculations)

Window	Cost/unit Dense City area	Cost/Unit Average density	Cost/Unit Undense area
1 Day (no window)	€2.75	€ 3.87	€ 4.17
4 hour window	€3.57	€ 5.04	€ 5.42
3 hour window	€4.40	€ 6.20	€ 6.67
2 hour window	€4.95	€ 6.97	€ 7.50
1 hour window	€5.77	€ 8.14	€ 8.75

The simulation results show that on average delivery costs with time windows can be considerably higher than for deliveries without time windows. Furthermore, if a B2C company decides to anyway offer time window deliveries, it may be recommended to offer these only in cities. A delivery in a city with a 4 hour time window is even cheaper than a standard delivery in non-urban areas (3.57 EUR versus 3.87 EUR). If offered to all regions (cities, average density and rural), one might need to ask a fee of 2 EUR to 4 EUR for covering the extra last mile costs.

3.3.4. Scenario 3: increasing the FTHR by increasing the number of office drops for B2C deliveries

This scenario shows the cost effects of concepts that try to deal with the high rate of not-at-home deliveries for cases where a signature is needed. An example can be to convince consumers to opt for a delivery at the consignee's working place. Hence, in the following table, an overview is given of simulated cost effects concerning changes in the first time hit rates. Reversely, if in the past no signature was needed and a company decides to introduce signature deliveries, the following cost might occur.

¹⁵ Scenario inputs density: City: >1,500 inhabitants/km²; average:333 inhabitants/km²; rural: <50 inhabitants/km²

Table 12: Cost effects of manned deliveries (Source: Own calculations)

FTHR	Costs/unit	FTHR	Costs/unit
75%	€ 3.87	90%	€ 3.23
80%	€ 3.63	100%	€ 2.91
		City 100%	€2.06

The simulation results show that, on average, having goods delivered at for example an office in the city can reduce costs significantly. This is a combination of the density characteristic and the manned vs. unmanned characteristic. A delivery within a city can reduce last mile costs by +/- 29% ($[2.91 - 2.06]/2.91$). A potential incentive can be to offer a shipping cost discount to consumers of up to 1.81 EUR for deliveries to working places in cities (3.87 EUR – 2.06 EUR).

3.3.5. Scenario 4: Only offering collection point deliveries

If it is not possible to increase the FTHR by delivering parcels to offices in the cities, a B2C player might consider deliveries to collection points in areas with an average population density. Hence, if it is assumed that a last-mile logistics company decides only to deliver to collection points, this implies that the first time hit rate increases to 100% as a first effect and that secondly one can assume that more parcels can be dropped at one collection point, which implies an increasing cp coefficient. An important remark is that one needs to take into account that a van has limitations concerning the maximum number of transported parcels. A maximum cp coefficient will be probably between 2 and 2.5¹⁶.

In the following table possible cost effects are calculated.

Table 13: Cost effects of collection points (Source: Own calculations)

Number of parcels per collection point drop	Cost
1 parcel	€2.91
1.5 parcels	€1.94
2 parcels	€1.45
2.5 parcels	€1.16

The simulation results show that by using collection points for B2C deliveries in urban areas one can converge towards very low last mile delivery costs, comparing with other potential B2C concepts.

3.3.6. Scenario 5: what can be learned from delivery costs in cities when using cargo bikes?

A new trend that can be noticed within B2C last mile logistics is the use of cargo bikes (Maes, et al, 2012). A cargo bike delivery implies lower distance costs, fewer kilometres driven but in densely areas possibly comparable numbers of stops/drops as vans.

If the following values are assumed:

- the d coefficient is only €0.05 (Maes, Sys & Vanelslander, 2012)
- The t coefficient is 17 EUR (Maes, Sys & Vanelslander, 2012)
- A bicycle courier delivers in a very dense area
- He/she drives around 50km per day (Maes, Sys & Vanelslander, 2012)
- He/she delivers 70 parcels per day (Maes, Sys & Vanelslander, 2012)

¹⁶ 2 parcels per stops (collection points) imply $2 \times 70 = 140$ stops. 2.5 parcels imply $2.5 \times 70 = 175$. The experts/interviewees stated that this is a maximum loading volume for a traditional van.

- He/she only works in dense populated urban areas: > 1500 inhabitants/km²

Then the last-mile delivery cost per unit is: **1.60 EUR**. If we compare this cargo bike delivery cost with a standard delivery cost within a city (2.91 EUR), we can state that a possible cost reduction up to 45% is possible in an urban environment using cargo bikes. As a result, if external costs would be taken into account (see paragraph further on in the text about future research), cargo bikes might be by far the cheapest (internal + external costs) option for urban last mile distribution.

4. Conclusion

The research questions to be answered in this article were: “*What are the potential cost effects caused by B2C last mile cost characteristics (cost drivers) in urban areas?*” and “*How can these costs per delivered unit be simulated?*”

To be able to simulate last mile costs and costs effects, a cost simulation tool was developed using inputs from earlier research findings. The authors already acknowledged that the main cost drivers within the last mile part of a B2C supply chain were: level of consumer service, security & type of delivery, geographical area & market density/penetration, fleet & technology and the environment. These cost drivers (‘*last mile characteristics*’) were used as independent variables within the cost simulation tool. This tool was developed using data from both academic sources and expert interviews and is based on a standard distance and time cost function. By extending this standard transport cost and time function by 13 major last mile extensions (1) to (13), the intended B2C last mile cost simulation tool was obtained (second sub research question). The last mile cost simulation tool developed made it possible to simulate last mile costs and cost effects.

When referring to the first research question, we can acknowledge that changes within the last mile (sub-) characteristics can cause significant cost effects within the last mile. For example, simulating the cost difference between a last mile delivery within a densely populated urban area (>1,500 inhabitants/km²) compared to a delivery in an average populated area (+/-333 inhabitants/km²) or a rural area (<50 inhabitants/km²) provided us with a possible cost difference of 5 EUR (2.75 EUR versus 7.75 EUR). Another simulation result that can be useful towards the logistics industry and city councils is the fact that time window deliveries in urban areas can be cheaper than standard deliveries within rural areas. The simulation results also emphasize the importance of high FTTH in B2C delivery routes. To conclude, with the developed last mile cost simulation tool, it was possible to deal with the articles’ research questions and obtained important insights in B2C last mile cost structures in urban areas.

5. Future research: B2C last mile external costs simulation

It is the aim of the authors to broaden this B2C last mile research towards external costs within the near future. The obtained last mile cost simulation tool can be used and extended towards a simulation tool for last mile external costs. More research needs to be done, but the intended approach is to add an **ap-coefficient** (average pollution coefficient) using emissions data (number of grams CO₂/km).

Last mile external costs per unit shipped =

$$\frac{(D \times \text{ict1}) \times (\text{ap} \times v)}{[(\frac{\text{STOP}}{w} \times (\text{ip} + b) \times \text{ad} \times \text{cp} \times Q \times p \times \text{pac})]} \times (1 + r)$$

This model will be the subject for further in-depth research.

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