The impacts of e-commerce growth on the amount of kilometers driven for last-mile delivery in the Netherlands

A system dynamic based analysis on the relation between e-commerce and the logistic sector

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Thesis report

by

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Preface

After many months of work, and even more years at the TU Delft, I can finally present you my master thesis. When downloading this last version of my master thesis, I saw that I downloaded 50 different versions of this document and I am pleased to present you this final version. The study aims to give insights in the impacts of the growing e-commerce market on the amount of kilometers driven for last-mile delivery by conventional delivery vans.

Firstly, I would like to thank Michiel de Bok for introducing me to this topic. It is a very interesting and dynamic topic, especially during the COVID-19 pandemic, where the use of e-commerce is the only way of shopping. I also would like to thank him as my TU Delft supervisor for his guidance during the research. Our weekly meetings helped me to stay on the right research path. Next, I would like to thank Floortje d'Hont for her guidance as System Dynamics expert and her constant energy to question my decisions regarding the transport elements of my system dynamics model. Furthermore, I would like to thank my other two supervisors from the TU Delft, Arjan van Binsbergen and Lori Tavasszy, for challenging me with new perspectives and for their clear feedback during the meetings.

I have been fortunate to do research in cooperation with the Kennisinstituut voor Mobiliteitsbeleid and would like to thank my supervisors Johan Visser and Stefan Verduin. I enjoyed the regular meetings with Johan and our discussions and his insightful stories about many other subjects. I also would like to thank Stefan for his phone calls to check up on me. I learned a lot from the meetings about Dutch policy research and from the feedback of the other colleagues during my presentations at KiM. Finally, I would like to thank my roommates, Dirk, my parents and my siblings for their support during the whole research.

A.S.M. Heinen
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Executive Summary

Introduction

In the last decade, e-commerce has grown considerably along with its impacts on the logistic sector. The growth can be explained by several factors, such as (older) people getting more familiar with internet and internet shopping and the use of online shopping applications for smartphones. External developments, such as COVID-19, influence the factors of e-commerce leading to even more use of e-commerce in this specific example. Online ordered goods are mostly delivered by delivery vans in the business to consumer (B2C) e-commerce sector and these transactions require, next to the transportation, also logistic planning of the deliveries. Competition between e-commerce suppliers lies mostly in logistic benefits for the e-commerce consumer, such as next day delivery and free return shipments, instead of lowering the prices of their goods for example. Logistic service providers have to be continuously more responsive to consumer demand. Furthermore, different types of last-mile deliveries, such as deliveries of small packages or the delivery of white goods that also need installation, have different types of logistic characteristics. In this example the amount of stops that can be made on a daily basis, the time needed for a delivery and the distance between the stops. All by all, the logistic sector has grown, as results of the growth of e-commerce, and also become quite complex due to these many components within this sector and the relation with e-commerce. The amount of kilometers driven by delivery vans for last-mile deliveries is 50% higher then the kilometers driven by vans for other activities. This transportation causes more pollution and mobility problems in urban areas. The total amount of kilometers driven for last-mile delivery by the conventional delivery vans are used in this research to estimate the impact on the environment and mobility for the medium to long term. The government can intervene with different types of instruments, and these can be used to change policy levers. Policy levers are in this system, the vehicle type, the allowed road speed and the delivery location. Figure 1 shows an overview of the main components and their relations towards each other.

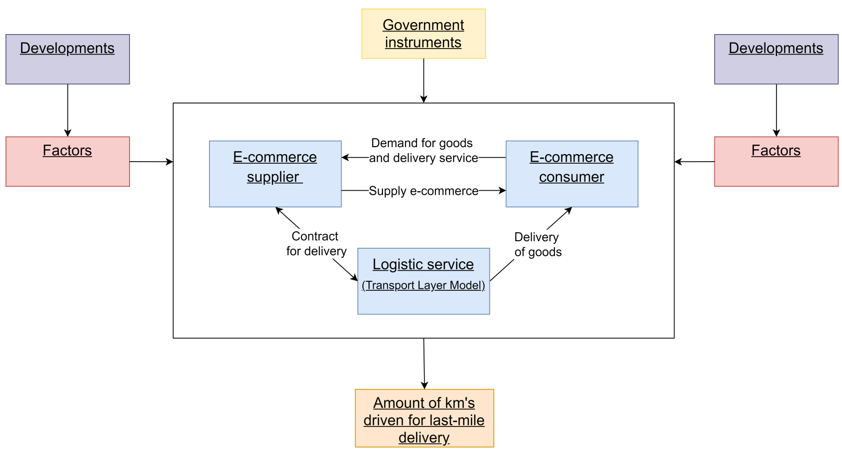

Figure 1: Simplification of the e-commerce market and logistic sector

Research Method

This research aims to give insights in the effect of e-commerce on the amount of kilometers driven for last-mile delivery by conventional delivery vans. This indicator is used to estimate the impact on the environment and mobility. A conceptual model, describing the relation between the e-commerce market and the logistic sector is used to clarify and analyze the different relevant links. A simulation model is build next to quantify the relations in the logistic sector. Both the conceptual model as the simulation model are build using System Dynamics. This method is able to structure and visualize the

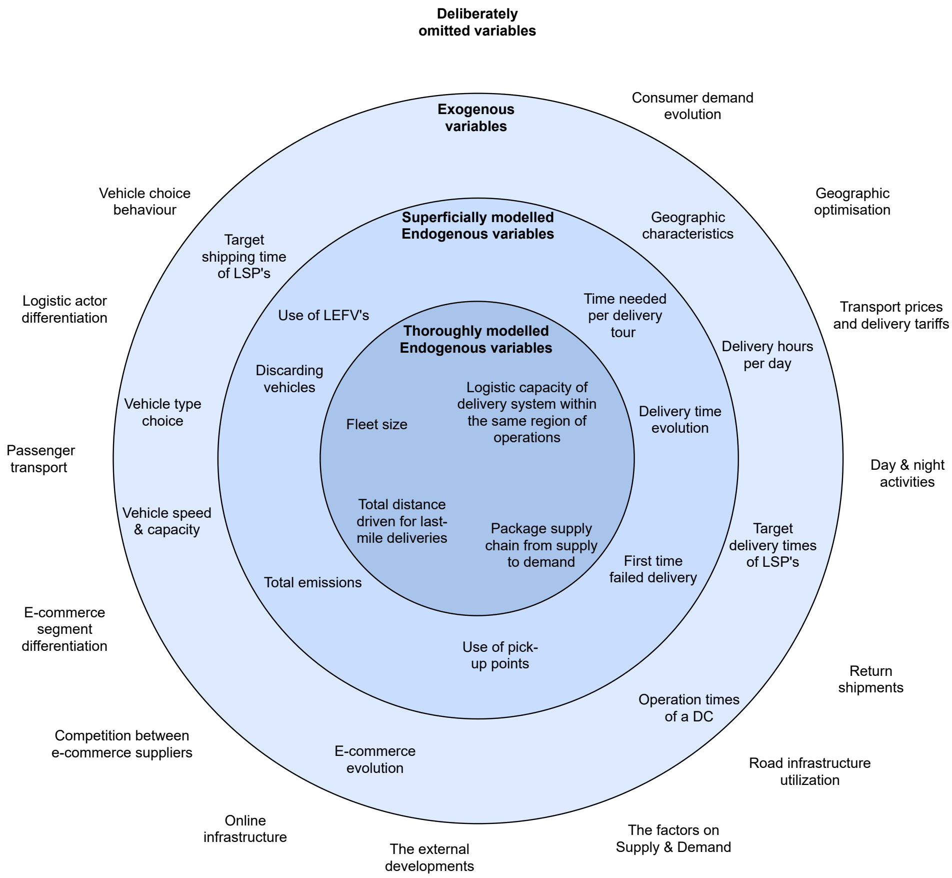

Figure 2: Bull's eye diagram illustrating the system boundaries

effects of decisions made in complex systems (Sterman, 2000), by illustrating the internal relations and structures and external interdependencies (Thaller et al., 2017). Clear visualisation of complex system can be very useful in a discussion about a system, it can be used as a communicative tool. The method can be used both qualitative as quantitative, with each way their advantages and disadvantages. The method was originally developed as quantitative model, but shortly after some argued that the quantitative aspect dominated the method whilst the other aspect of the method, 'system thinking' or 'qualitative system dynamics', was also valuable. Where qualitative models are quite strong in mapping structures and feedback loops, they could also be misleading in their insights, which can intentionally be used by people, or when people are inexperienced with the method. Quantitative models can illustrate behaviour of a system over time by using non-linear, differential and integral equations, and only little data. Validating such models can be quite complicated and sufficient experience is needed to do so (Wolstenholme, 1999).

The conceptual model is used to extract the most relevant relations within the logistic sector. First, the most relevant variables of the conceptual model are placed in a Bull's eye diagram (Figure 2 to illustrate the system boundaries. Next, the relations of the inner circles of the Bull's eye diagram, are visualized in a Causal loop diagram (CLD) shown in Figure 3. Variables can have a positive relation, which means that an increase of variable A leads to an increase of variable B. Variables can also have a negative relation, this means that an increase of variable A leads to a decrease of variable B. The sign on the arrow (+ or -) indicates if the relations is positive (+) or negative (-). A third sign on the arrow, ||, indicates that there is a delay in the relation. The arrows in this CLD are also color coded for the purpose of explanation. The blue arrows display the simplified supply chain of the delivery of packages, the red arrows display the effect of e-commerce growth on the logistic operations behind the delivery of the packages. The black arrows complement the blue and red arrows. All variables are black, except for one orange variable, this variable refers to the amount of kilometers driven for last-mile delivery by delivery vans, which is the main indicator of the model.

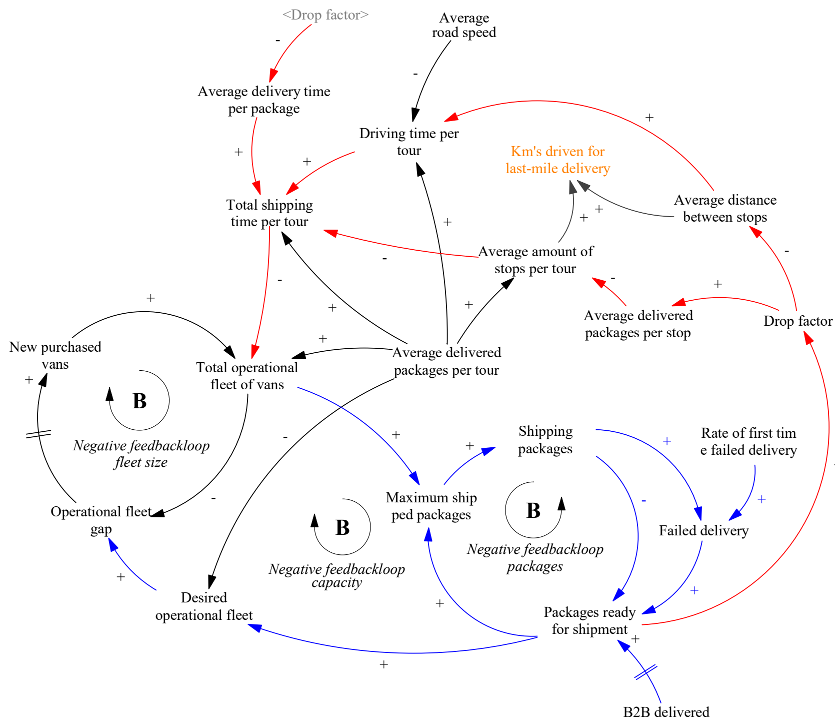

Figure 3: Causal Loop Diagram showing the relation of e-commerce demand and the logistic sector

A growth of e-commerce, represented by the *B2B delivered packages*, results in an increase of *Operational fleet gap*, according to the series of blue arrows. Via the *Negative feedback loop fleet size* this gap decreases. The increase of *B2B delivered packages* also results in more packages that can physically be shipped, *Maximum shipped packages*, when enough vans are available, *Total operational fleet of vans*. Eventually more packages are shipped, *Shipping packages*, which decreases the *Package ready for shipment* and closes the two other feedback loops (*Negative feedback loop capacity* & *Negative feedback loop packages*. The growth of e-commerce leads to a higher *Drop factor*, the amount of packages delivered in the same size area. The *Drop factor* influences three variables (*Average delivered packages per stop*, *Average distance per stop* and *Average delivery time per package*), which combined leads to a decrease of *Kilometers driven for last-mile delivery* (in orange). Concluding, even though there is an increase of e-commerce, this does not lead to an equal increase of transportation based on the insights of this CLD.

System Dynamics Model

The CLD is a qualitative model, next the relations are quantified in a simulation model. The goal of the model is to establish the effect of the e-commerce growth on the amount of kilometers driven for last-mile deliveries and to establish the effect of the government instruments on the amount of kilometers driven for last-mile deliveries. This output is used to represent the impacts on the environment and mobility, along with other indicators. Policy levers are represented by the parameters shown in the first row of Table 1. Policy strategies are formed based on the policy levers, and are analysed on their effect on the indicators. First, assumptions are made to set the model boundaries, these assumptions are based on the conceptual model and the CLD. Next, mainly data from CBS and ACM are used to quantify the model variables. For variables without a clear value, assumptions are made.

In the base case, the model simulates 18000 days (50 years). *E-commerce growth* grows 15% per year at the start of the simulation and will eventually slow down, which results in a s-shaped curve (ACM, 2020; L.A. Martin, 1996). After 50 years, the demand for e-commerce has thus increased with 381% in comparison with the beginning of the first year. This growth parameter is the main system boundary of the SD model. Next to the indicator, *Daily distance driven for last-mile delivery*, four other indicators are defined (see Table 1), the behaviour of all indicators says something about the effect of the growth of e-commerce and its impact on last-mile deliveries. In the next figure (Figure 4, the behaviour of the *E-commerce growth*, the *Total operational fleet of vans* and the *Distance per package* is shown as an illustration of the model output. In the figures the change after 50 years is included. The rate says nothing about the development of the KPI over time, these rates are used to indicate whether the KPI will increase or decrease eventually. The rates of the other indicators are shown in the Table 1 and illustrates also the sensitivity of relevant parameters on the KPI's by color. This sensitivity indicates the effect of the policy levers. Green indicates that the parameter influences the corresponding KPI, yellow indicates little influence and no color means very little to no influence in the SD model. A change of the *Van capacity* will thus influence the *Daily distance*, the direction of the change is not shown by the colors.

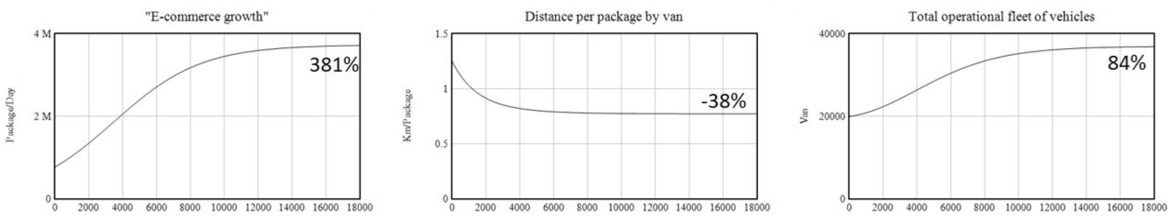

Figure 4: Behaviour of *E-commerce growth* and two KPI's in the base case

Table 1: Overview of KPI's in Base Case and their sensitivity for model parameters

Indicator	Start value	Base case [50 years]	Van capacity	Rate of first time failed delivery	Average delivered packages per stop	Initial stops per kilometer	Average road speed	Package delivery time
B2C demand [package/day]	*770000*	*381%*						
Daily distance [km/ day]	1200000	217%						
Total emissions [CO_2]	0	N.A.						
Total fleet of vans [van]	20000	84%						
Distance per package [km/ package]	1,25	-38%						
Total shipping capacity [package/day]	800000	385%						

The *Distance per package* is decreasing, which indicates that some logistic efficiency is gained due to the growth of e-commerce. Also the *Total operational fleet of vans* did not increase as much as the growth of e-commerce (84% versus 381%). The *Total shipping capacity* needed to deliver all packages increases more than the growth of e-commerce. 25% of all deliveries is not deliver the first time, which results in the need of more capacity than initially needed. The *Rate of first time failed delivery* is therefore also the only parameter that influences the *Total shipping capacity*. Furthermore, the table shows that the parameter *Van capacity* influences most indicators. This parameter can vary a lot with different sized packages. The *Average road speed* and the *Package delivery time* have the least influence on the indicators.

Policy Strategies

Next to the effect of the individual instruments, the effect of combined instruments is researched. Two policy strategies are researched based on the available levers in the model and on actual solutions.

Both strategies are separately simulated in and are at the start of the simulation not active. Once the threshold for *Daily emissions* is passed, the strategy becomes active. The presence of the strategy is as strong as the difference between the threshold for daily emissions and the actual *Daily emissions*. Figure 5 illustrates the implementation of the policy strategies.

The first strategy describes the use of (unmanned) pick-up points with the characteristics shown in table 2. The model simulates only the use of pick-up points by delivery vans, the passenger transport needed to pick-up the packages is not simulated. The use of pick-up points increases the logistic efficiency, more packages are delivered per stop and the so-called *first time hit rate* increases. Less total shipping capacity is needed which leads to less kilometers driven for last-mile deliveries and less traffic. Pick-up points are also an easy exchange point for return shipments, less empty trips will probably be made when combining these shipments. This will optimize the delivery even more. Pick-up points are of most value when a lot of packages can be dropped of at once. In dense areas, the logistic operations are already quite optimized in this domain, since the amount of households met km^2 is higher, and the drop factor is thus generally higher than in sparsely populated areas. It is therefore more favourable to place pick-up points in these type of areas. However this could also mean that consumers have to walk further to pick up their package, which is less desirable.

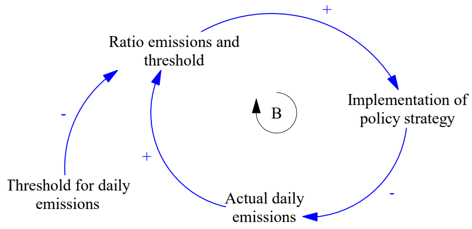

Figure 5: Implementation of policy strategies

Table 2: (unmanned) Pick-up point strategy

Variable	Value base case (delivery van)	Value pick-up point
Rate of first time failed	25%	5%
Average delivered packages per stop	40 packages	40 packages
Distance between stops	500 m	0 m
Base distance from DC to neighbourhood	2x15km	2x20km
Package delivery time	4 min	1 min

The second scenario discusses the use of light electric freight vehicles (LEFV), shown in table 3. This scenario does not necessarily optimize the delivery system, like pick-up points do, but it does improve the impact of the last-mile transportation on the environment and mobility. Firstly, LEFV's are much cleaner than conventional delivery vans are and have thus less impact on the environment. Furthermore, more traffic movements are made, since the capacity (packages/vehicle) is lower for LEFV's, which is also illustrated by the indicator *Daily driven kilometers*. However their ability to drive on bicycle lanes, reduces the amount of traffic movements on roads. LEFV's are smaller and can easily park on the side road, and less spaces is therefore occupied. Space is scarce in dense areas and delivery by conventional vans can lead to congestion in these areas, these smaller vehicles are thus a favorable solution for dense urban areas.

Table 3: Light electric freight vehicle strategy

Variable	Value base case (delivery van)	Value LEFV
Base distance from DC to neighbourhood	2x15 km	2x10 km
Packages delivered per tour	40 packages	10 packages
Average road speed	20 km/h	20 km/h
CO2 per km	0,3 gram/ km	0 gram/ km
Average package delivery time	4 min	3 min

The effects of both strategies on all indicators are shown in table 4. The indicators *Daily distance* and *The total operational fleet* both only show the values for the conventional delivery vans. The amount of kilometers driven by LEFV's and the amount of LEFV's is not indicated in this table. Seperately, the implementation of LEFV's will reduce the amount of emissions the most in comparison with the use of pick-up points. The use of pick-up points however, reduces the *Total shipping capacity* needed, and therefore the amount of vans needed. Also, the combination of both strategies is simultaneously simulated and shown in the last column of Table 4. The strategies complement each other, as the total amount of emissions is the lower. Due to the set up of the policy implementation (Figure 5, the strategies are implemented to a lesser extent. The amount of daily emissions is lower and thus less policy is needed to reduce the amount of daily emissions.

Table 4: Changes of KPI's per strategy

Indicator	Start value	Base case	Pick-up point	Light electric freight vehicle	Combination of both strategies
B2C demand [package/day]	*770000*	*381%*	*381%*	*381%*	*381%*
Daily distance by vans [km/day]	1200000	271%	150%	233%	217 %
Total emissions [CO_2]	0	16 B	14 B	13 B	12,5 B
Total fleet of vans [van]	20000	84%	50%	62%	44%
Distance per package [km /package]	1.25	-38%	-46%	-31%	-34%
Total shipping capacity [package /day]	800000	385%	331%	385%	348%

Conclusion

E-commerce influences the logistic sector in different ways. The growth of e-commerce leads to more use of transportation, but also results in more logistic efficiency of this transportation. The amount of consumers increases and also the demand per consumer increases. This results in shorter distances between the stops and to more packages delivered per stop, which increases the efficiency of deliveries. This efficiency will however not continue indefinitely and the negative impacts on the environment and mobility will grow continuously. The government can use several instruments on levers within the last-mile delivery system. Van capacity, first time hit rate and the amount of packages delivered at once per stop are the most influential levers within this research scope. This means that the government should look into the available instruments and their influence on these parameters. A campaign to create awareness among citizens to stay home when they expect a package, could for example help to increase the first time hit rate. Using (unmanned) pick-up points leads to less needed shipping capacity, due to the impact on the first time hit rate, and thus less impacts on the environment and mobility. The usage of LEFV's complementary to the use of conventional delivery vans results in less pollution.

Limitations & Further Research

The research give insights in the relation between e-commerce and the amount of kilometers driven for last-mile delivery. However there are also limitations of these insights. The limitations of the research are discussed by theme. The last paragraph discusses possibilities for further research.

Results

The research question is focused on freight transport, however passenger transport is also part of the system. These should decrease with the rise of e-commerce, but this is not incorporated in the scope and therefore no conclusions can be drawn about the whole effect of e-commerce on the effect on the environment and mobility. Next, the urban characteristics of an average city are used in this research. This can results in excluded gains and losses of the efficiency of last-mile deliveries. The model simulates only one type of urban area, an average urban area, and thus an average amount of logistic efficiency probably. Furthermore, for every vehicle the same amount of packages in the vehicle is assumed. The amount of packages loaded in the van can vary for several reasons, like size of package, loading tactics or simply the demand on that day. Additionally, the model is quite sensitive to this variable, which makes it an important system boundary. Another limitation concerns the lack of differentiation of the e-commerce segments. The system dynamic model simulates the effect of e-commerce growth for the average segment, this shows the general effect of e-commerce growth on the amount of kilometers driven for last-mile delivery, whilst every segment is differently influenced by the growth of e-commerce. Finally, the amount of kilometers driven for last-mile delivery is used as main indicator for the effect on the environment an mobility in the Netherlands. By translating the amount of kilometers directly to the impact on the environment and mobility, a very linear relation is used which does not reflect the whole relation.

System Dynamics
In this research, a combination of different aggregation levels was used to simulate the system correctly. On a low aggregation level, transportation has often discrete characteristics which influences the high aggregation level. Every day decisions are the main drive of the system behaviour in this system dynamic model. The medium term influence of e-commerce growth on the amount of kilometers is therefore illustrated. However macro effects and macro behaviour are less represented in the model, like the behaviour of the fleet when new policy is implemented. Related to this discussion, is the next point of discussion. The system dynamic model does incorporate different vehicles and delivery options at the same time. However only superficially, the policy implementation is based on a simple environmental threshold. The use of electric vehicles might be more sustainable, but they are less familiar currently and require a higher investment. The choice behaviour of the logistic service supplier is therefore also relevant. Using pick-up points might also be better, but if consumers are not willing to adapt, this strategy will not be as effective as concluded. Agent Based Modelling (ABM) could also be used to model this system from bottom-up instead of top-down. The emphasis of such a model lies on the interactions between the different actors instead of the overall behaviour of the system. This makes it a appropriate method to simulate the discrete elements of a transport system and of the lower aggregation level of this research system. The two methods are complementary, ABM could be used to simulate lower aggregation level and the results can then be used in the SD model for the higher aggregation levels in further research.

Data
The model simulated the average urban city and the average e-commerce segment regarding the freight market, general data was therefore enough. As just mentioned, the model could benefit from more differentiation in the e-commerce segments and urban areas. Currently, CBS administers only several branches in online sales, while more segments are identified in literature, such as general cargo or temperature controlled cargo. Also, the type of e-commerce, B2B or B2C, was not always mentioned, which can easily to big differences in data sets.

Further Research
The dynamics with passenger transport were excluded in this research, further research could evaluate the dynamics between passenger transport and freight transport. Also, less freight transport to physical shops is probably needed to deliver the inventory. The influence of this freight flow on the amount of kilometers driven for retail purposes, could also be researched. Furthermore, the influence of time and location of the transportation is not included, whilst this can have great influence on daily congestion. Further research could add spatial and/ or time of day distribution. Next, the optimization possibilities of delivery systems in different urban areas can be researched. The density of an urban area, can lead to more logistic efficiency whilst rural areas to less efficiency of transportation. The same type of research can be conducted for the different e-commerce segments and the possible business strategies within every segment, to get a better understanding of the behaviour per segment. Literature indicates the little amount of system dynamic research in the transport field of research, however reasons for this event are not given. Further research could investigate possible reasons and summarize causes for this in a paper. Next, macro behaviour between e-commerce and the logistic sector is little simulated in this model. Additional research could focus on system boundaries on a more aggregated level. Finally, further research could gather data related to specific e-commerce segments, like the average amount of deliveries or stops per day and the size of the region of operation.

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List of abbreviations

B2B	Business to business
B2C	Business to consumer
C2C	Consumer to consumer
CEP	Courier, express & parcel
CLD	Causal loop diagram
DC	Distribution centre
E-commerce	Purchasing or selling products online
KPI	Key Performance Indicator
LEFV	Light electric freight vehicle
SD	System dynamics
TLM	Transport layer model

1 Introduction

Freight transport and logistic services are important backbones in the Dutch economy (Ministerie van Infrastructuur en Waterstaat, 2020). A strong and robust road network, to reduce possible time loss during disturbances, is thus key for the businesses depending on it, also the environmental and traffic impacts of the logistic sector are significant (Ministerie van Infrastructuur en Milieu, 2018). Currently, the logistic sector has to cope with several developments, like the need for sustainability, the wish for livability, the rise of technical innovations (Boer et al., 2017) and finally the considerable growth of e-commerce. These different factors influencing the logistic sector, makes it challenging to estimate the individual impacts of these developments on the environment and mobility.

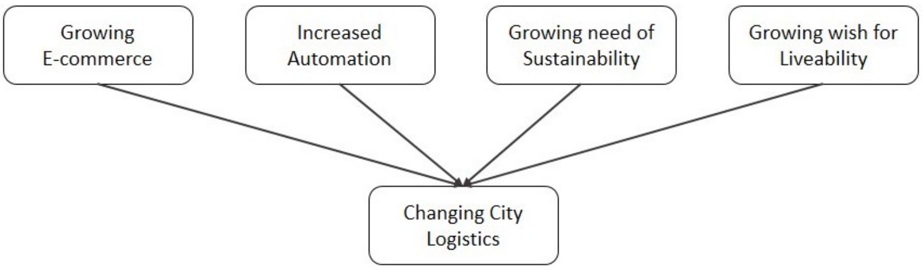

Figure 1.1: Developments city logistics

In 2012 the growth of e-commerce and its economic impacts were described in a green paper of the European Commission. The green paper addressed the need to examine the key challenges and opportunities in Europe of e-commerce. A follow up mentioned a 20 percent growth of the e-commerce market, which is estimated at a value of 250 billion Euros now (Copenhage Economics and European Commission, 2013). Connekt, a Dutch research network, confirms in 2017 a growth of e-commerce in the Netherlands of 20 percent. Allen et al. (2018) discusses the factors influencing this growth, examples are, older people getting more familiar with online shopping, young people raised up with internet, the rise of smart phones and online shopping applications, less physical shops due to the high competition with e-commerce and so on. The rise of e-commerce is undeniable and this causes changes in the logistic sector, like for the conventional logistics patterns (Ducret, 2014). Transport flows are shifting from distribution centres (DC) to stores, to more transport flows towards individuals in neighbourhoods (Allen et al., 2018).

The most used delivery vehicles for e-commerce are vans, especially in the business to consumer (B2C) e-commerce. The 20 percent growth of e-commerce will consequentially also influence the amount and the amount of these delivery vans. The amount of kilometres per year driven by delivery vans is currently 50 percent higher than for vans used for other purposes, however its share in the total transport market is still under the five percent. Furthermore the amount of delivery vans is not increasing as much as would be expected (CE Delft, 2017). Extensive studies about the use of delivery vans are little available, an explanation for this availability could be that this type of vehicle has fallen between two stools. Freight transport mainly focuses on trucks for road transport and passenger transport does not study the use of freight transport via delivery vans (CBS, 2016). This does not mean that they are also not needed, in the contrary, their need is increasing with the mentioned developments going on. Researchers have expressed their concerns regarding the changes and its impacts on logistics, most of these concerns regard the increase of traffic, in mainly urban areas which causes more congestion (partly due to parking of vans in narrow streets during a delivery), a decrease in traffic safety, and an increase of emissions (Visser et al., 2014; World Economic Forum, 2020). Based on data from the CBS, vans in cities would have a large share in emissions (CO2, NOx and PM10) (Kim & CBS, 2019).

In 2014, the initiative Green Deals started, part of this initiative is to have emission free city centres (Greendeals, 2020). However it is not clear whether this is feasible with the significant growth of e-commerce, its impact on urban areas, and with at the same time the other mentioned developments going on.

One of the strategies is to use an integrated approach, consequently an overview of the whole system is needed. Research regarding the effects on the overall system, the involved stakeholders, the macro effects and their magnitude are repeatedly mentioned as lack of research by the above mentioned literature. But also research about the use of vans is lacking: the goods transported, the amount of stops, the time of day, the reason of transport, etc. (Kim & CBS, 2019). The complexity of parcel operations (delivery windows, routing, etc.) is also little researched. Altogether causes local and national authorities to have difficulties creating a policy to control the negative externalities of the e-commerce growth (Allen et al., 2018).

A descriptive model with a holistic view of the delivery system will help to fill in a first set of knowledge gaps, the model will also clarify relations and impacts. Additional, new trends and developments, general trends and within city logistics, should also be taking into account to have a complete view, like the prominent COVID-19 crisis and the implementation of cargo bikes. The Central Bureau for Statistics (CBS) in the Netherlands has addressed the need of more data about the use and ownership of vans. A large research is setup together with different governmental institutions. This collaboration was the start in the process of filling in the above mentioned knowledge gaps.

This research proposes a research of the relations between the e-commerce sector and the amount of kilometers driven for last-mile delivery, and with B2C e-commerce as main determinant. The impact of e-commerce on the amount of kilometers driven for last-mile delivery will then be used to estimate the impact on the environment and mobility. Factors and developments influencing the parcel delivery system will also be analyzed. The policy levers and an analysis of strategies will also be done to get insights of the political possibilities. The thorough analysis of the current situation will show the relations between the different factors and the current possibilities of the government to anticipate on the e-commerce growth.

1.1. Objectives and Research Questions

The growth of e-commerce will affect the parcel delivery sector and will affect current city logistics environmentally (air quality), economically (efficiency of delivery vans) and spatially (land use) (Mokhtarian, 2004). The specific underlying factors and their magnitude on the emissions and congestion are unknown, therefore the objective is to describe and to clarify these. This will be done by analysing the current system and by creating an understanding of all relations and developments. Eventually this will help authorities to anticipate on future challenges. A conceptual model will be designed and will be used to map and identify the relations concerning deliveries and e-commerce and its effects. The conceptual model will be a guideline for the quantification of the effects and of the relations shown in the conceptual model. Then, the simulation model will be the output of this quantification, and this model will be scoped beforehand based on the most relevant relations. It will also be an instrument to check the consistency between different data sources and research, and to help with the development of the CBS survey for the next years. The main research question is the following, the sub questions are shown below the main research question.

How will the growth of the B2C e-commerce demand and supply, influence the impacts on the amount of kilometers driven for last-mile delivery by conventional delivery vans in the medium to long term?

1. How can the relationship between e-commerce demand and the corresponding logistic sector be described qualitatively?
2. How can the relationship between macro-effects and micro-behaviour be described qualitatively?
3. What are the likely quantified impacts of e-commerce demand on the amount of kilometers driven for last-mile delivery by conventional delivery vans?

4. How can policy anticipate on the e-commerce growth to minimize the impacts on the environment and mobility?
5. Which improvements can be made in the CBS survey for the next years to gain more consistency of data?

1.2. Scope

In this chapter the scope of the research will be described, this defines the width and the depth of the research. The objective and research questions describe already some limits: the objective aims to help Dutch policymakers so the scope is logically limited to the delivery system in the Netherlands, The desires of the Dutch government are used as guidelines for the impacts that are considered. The impacts of e-commerce will thus focus on environmental and mobility impacts, vie the amount of kilometers driven for last-mile delivery, these affect people the most and are therefore considered (Ministerie van Infrastructuur en Waterstaat, 2020). Other subjects in the research that determine the scope will be discussed per theme, first the scope concerning e-commerce will be discussed, followed by the Distribution flows and lastly the actors within the research. This research is part of a graduation thesis and is therefore also limited to time constraints.

1.2.1. E-commerce

Purchasing and selling goods and services online is the concept of e-commerce. In this report not all segments of e-commerce are part of the scope. Goods transported to homes are the main subject, however there are different types of goods and these differences influence several characteristics from the supply chain, like the type of vehicle and the delivery time. In the following graphic a table (Table 1.1) is shown with the different segments and markets for goods, which are (partly) delivered by delivery vans, and thus relevant for this research. The table indicates the magnitude of each market segment by kilometers. The corresponding freight type and characteristics are shown as well. Finally a column with the influence of e-commerce is shown in the table, this can indicate future change (CE Delft, 2017). This table is used to indicate the differences between the different e-commerce segments, which will come back in the conceptual en simulation model.

1.2.2. Distribution Flows

Other limits of the research scope regard the chosen type of transaction and distribution flows. The most important factor that decides whether a flow is considered or not, is the type of mode of transport that is used, in this case: all types of conventional delivery vans. Business to consumer (B2C) transactions are mostly handled by vans and this type of transaction is therefore also the most relevant, as also previously shown in Table 1.1. The corresponding distribution flows are shown in next figure (Figure 1.2) combined with the possible return flows. The figure shows the starting point, a distribution centre (DC), and the arrival point, households. Stops in between are also shown, like smaller DC's or pick-up points. Furthermore the different types of vehicles that can be used are shown to indicate the variation of possibilities next to the use of conventional delivery vans.

Many customers return their ordered goods, especially in women fashion. The return rate of this segment is currently estimated at 41 percent (Thuiswinkel, 2020b) . The Netherlands has the highest return rate from Europe and this high amount of returns is affecting the delivery system negatively (Logistiek.nl, 24-7-2018). Some company's pick-up returns in their usual delivery rounds, whilst others have a separate system (UPS, 2020). It can be assumed that for both manners vans are used. Adding both the high return rate and the transport mode, leads to the consideration of return shipments in this research. The return flow will be seen as a separate flow from the delivery flow. As shown in the figure, B2B flows are not within the scope. C2C transactions are more complicated, these types of transaction are either done by consumers themselves or handled by a third party that is contacted, like PostNL. When a third party provides the transport, then delivery vans are a common mode of transport, this segment is growing but not as fast as B2C e-commerce (PostNL, 2015; Weltevreden and Rotem-Mindali, 2009). You could argue with this information that this flow should be considered, however this flow can also already be integrated in the sector Parcel deliveries. The transaction is done by delivering the package to a PostNL point, in this example, from where the package is integrated in the PostNL delivery system. Due to this ambiguity, C2C transactions are not considered individually.

The research will also consist of an analysis of current and future developments and their impacts

Table 1.1: E-commerce segments and markets of freight, based on the Connekt Annual Outlook 2017

Segment	Market	Size (in mil.km)	Delivery van (% within market)	Freight type	Freight market characteristics	Influence e-commerce
General Cargo	Home delivery	X	X	Large heavy goods	Delivery with time slots, receiver must be home	High
	Small independent stores	1356	32	B2B transport of goods	Small, JIT deliveries	High
Temperature Controlled	Wholesale food	584	18	Non-perishable and fresh food	Medium volumes per customer,	Low
	Specialists	150	100	High-value products	Low volumes, non-scheduled deliveries	Medium
	Home delivery	45	100	Food, and food-boxes	Different strategies of flexibility (Picnic vs. AH e.g.)	High
Parcels & Express		106	86	Parcels or high-value express mail	Few large players with high drop density,	High

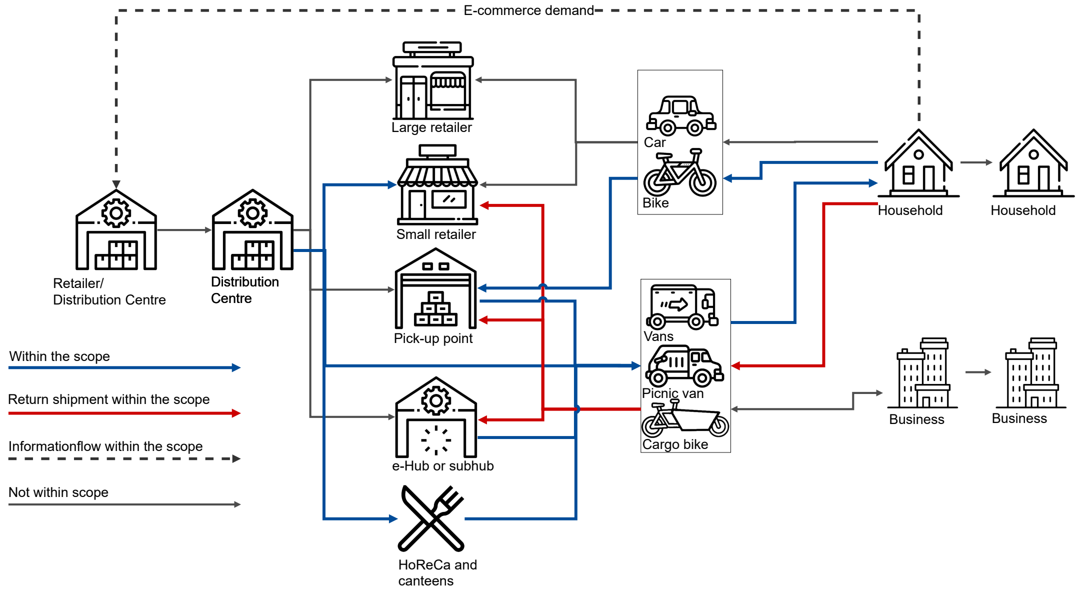

Figure 1.2: Distribution flows

on the amount of delivery vans. The most prominent development is the COVID-19 crisis, which will most certainly lead to a weakened economy but also to more e-commerce (Taylor and McCombe, 2020) and is therefore thus a very important development for this research. This development will be incorporated by adapting the demand of e-commerce.

1.2.3. Actors

The most relevant groups of actors in the field of e-commerce are the retailers, otherwise specified as the e-commerce suppliers, the customers and the logistic party that delivers the products. The role of logistic service provider and retailer can be done by the same party, as Albert Heijn or Coolblue do. The government is the fourth stakeholder, they are the problem owner in this thesis because the impact on the society is researched.

1.3. Methodology

The research objective consists of several sub-research questions (SQ). To answer these SQ's the following steps are taken. In this chapter these steps are discussed on chronological order of the research, see Figure 1.3. The numbers in brackets refer to the sub-research questions from section 1.1.

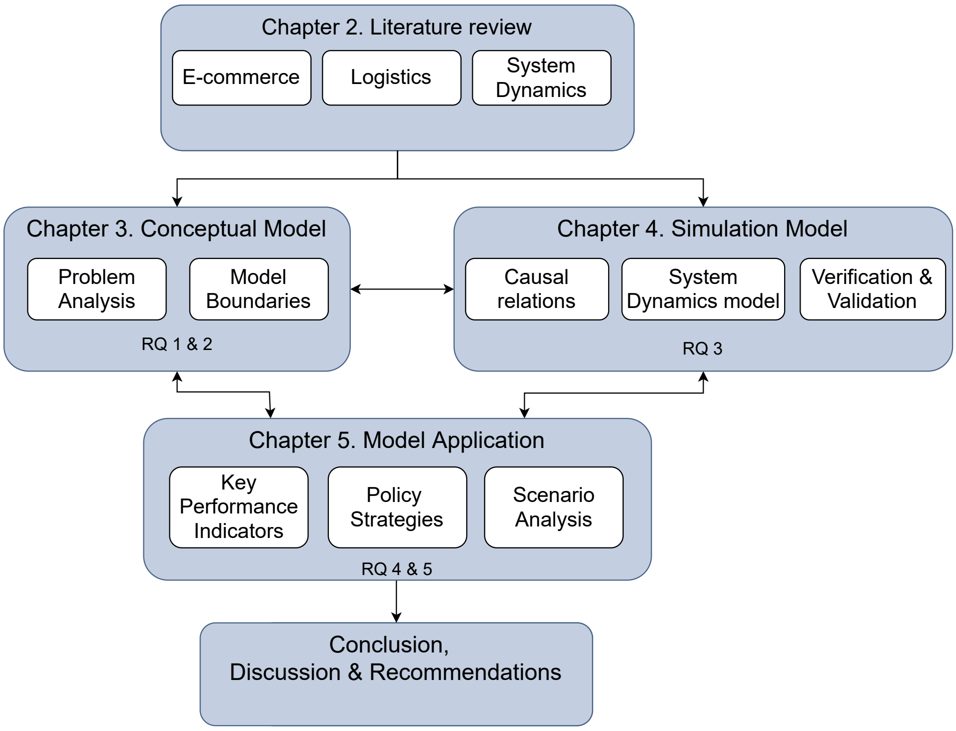

Figure 1.3: Thesis structure

1.3.1. Literature Review

Firstly a literature review is done to create an overall and deeper knowledge of the subjects concerning the research. The link between e-commerce and the logistic sector is researched to get insights about their influence on each other. These insights are used to describe their relationship qualitatively, which is needed for the first research question. System Dynamics models are analysed to get an overview of the existing transport models in the system dynamics field of research and system dynamics transport models are used as inspiration for the system dynamics model of this research. Literature like scientific papers and policy documents are the foremost source of information. Policy documents are mainly found on the database of the Dutch ministry of Infrastructure & Water management (www.rijksoverheid.nl/ministeries/ministerie-van-infrastructuur-en-waterstaat) and the database of the Kennisinstituut voor Mobiliteitsbeleid (www.kimnet.nl/). This type of literature is needed in the problem analysis and for the model application. Science Direct (www.sciencedirect.com/) and the System Dynamics society (www.systemdynamics.org/) are mainly used to find scientific papers, which are also used in the problem analysis to identify and describe the causal relations. E-commerce supply and demand factors and freight transport models are discussed in the problem analysis and are therefore also two main subjects for the literature review. The third subject will be about system dynamics, as can be seen in the Figure 1.3.

1.3.2. Problem Analysis

The chapter Conceptual Model, describes the problem analysis and sets the system boundaries for the simulation model, this is referred as the Problem description and Conceptualisation in Figure 1.4. The description of the relations between e-commerce and the logistic sector is used to answer research questions one and two. Dutch policy papers and scientific theories are used to form a framework for the problem analysis. Part of the conceptual model, is the effect of policy levers. Policy documents are used to identify the current policy levers. These instruments are again used to evaluate policy strategies further on in the model (in the Model Application). The problem analysis is used to establish the most relevant causal relations. These are thereafter described in a causal loop diagram (CLD). This diagram is the first step in the development of the simulation model using system dynamics and is an important step for the specification of the model. All steps taken are shown in Figure 1.4, and are further discussed in the next paragraphs.

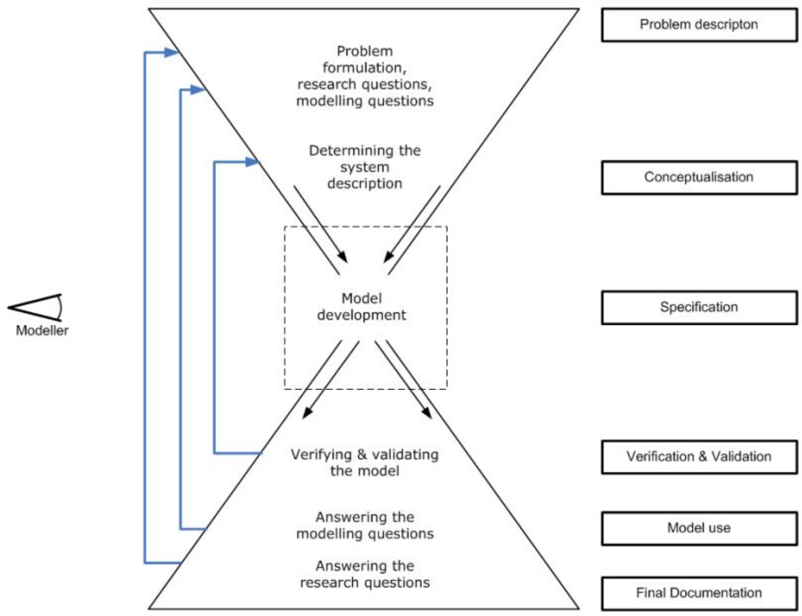

Figure 1.4: System Dynamics methodology (based on Slinger, 2014)

1.3.3. System Dynamics

From Introduction, Objectives and Research Questions and Scope can be deducted that different dynamics are part of the whole system. The distribution of packages in urban areas can be described as complex or 'wicked' (KiM, 2017), the different components in the model act and react on each other. The growth of e-commerce is, for example, caused by more people using online shopping and by a higher demand per person. This leads to more served households per area and to more packages delivered at the same time per household. Both influence, in their own way, the delivery tour characteristics and the amount of delivery vans needed to deliver all packages. Such dynamics are relevant in the search for the influence of e-commerce on the amount of kilometers driven for last-mile delivery. System Dynamics (SD) is a method which can easily visualize the different relations of the variables in a system and where the dynamics like feedback loops within the system can be described (Sterman, 2000). Clear visualisation of complex system can be very useful in a discussion about a complex system, it can be used as a communicative tool. Also simulation of the system can be part of system dynamics when the level of certainty of the input values is high enough, otherwise wrong conclusions can be drawn from the model (Coyle, 2001). First, the conceptualization of the system will be done using SD. This method stimulates holistic and systematic thinking (Pruyt, 2013) which is needed for the conceptualization of the system. A conceptual model, illustrating the different elements and the link between these elements, will be an output of the conceptualization phase. A Bull's eye diagram will also be an output of the conceptualization phase and is used to illustrate the system boundaries. These boundaries are needed for the specification of the SD model.

In Chapter 3 the framework behind the model is described by first making a Problem Analysis and illustrating the system boundaries in a Bull's eye diagram. The next step in the model development is a specification of the model, including a map of the causal relations, determined in the conceptual model, in a Causal Loop Diagram (CLD). Assumptions are used to narrow the system scope and modelling questions are asked to define the model purpose. The specification and the simulation of the scoped system, based on the findings of the conceptual model, is discussed in Chapter 4. In the quantification phase, literature is used again and qualitative data: raw data from CBS is used, processed data from the CBS in the report *Gebruikers en inzet van bestelauto's in Nederland* CE Delft (2017), and other quantitative data from Post & Pakketten monitor of Autoriteiten Consumenten Markt (ACM) is used. Assumptions are made for variables without clear determined values. By doing this, gaps in the CBS data can be found and recommendations can be formed to fill these gaps. The analysis will consist of a more detailed analysis of specific relationships in the conceptual model and behaviour of the model will be discussed. Research question three is answered in this chapter.

The validation and the verification focuses on the models fit for its purpose. Model verification is used to get insights in the sensitivity of certain links and parameters. Uncertainties within the model will be identified and their influence on the model results will be determined. This step is needed for the discussion of the model results. Part of the verification is thus a sensitivity analysis, among other tests from J. Forrester and P.M. Senge (1980), where factors and their behaviour are tested on their influence on the system. Sense for real-life behavior, existing models and insights from experts will be used to verify and validate these factors. An expert on urban freight distribution (dr. Ron van Duin) can help in this stadium. A deviation will be made between literature values and the ones that are estimated or assumed.

1.3.4. Policy Strategies

Furthermore, an exploration of the policy levers, which influence the amount of kilometers driven for last-mile delivery, will be done. Governmental institutions can for example speed up the implementation of electric cargo bikes by granting subsidies for such vehicles or make the implementation of pick-up points on municipal ground less complicated by adapting the permit application. An overview of all relevant government instruments and policy levers is shown in the problem analysis. Due to the specification of the model, not all policy levers will be part of the simulation model. The policy levers still available in the specified model will be used to form different strategies. The chapter Model Application will provide different strategies, the use of (unmanned) Pick-up points and the implementation of Light Electric Freight vehicles, using policy levers on different levels. Their effect on the amount of kilometers driven for last-mile delivery will be analysed, and their effect on the total amount of emissions caused by last-mile delivery. Policy documents and current trends are used for the formation of these strategies. The strategies will be simulated in the specified simulation model as strategies and the results are used to answer the modelling questions and research question four. Scenario's will be build, based on exogenous variables of the SD model, and used to determine the bandwidth of the effects on the amount of kilometers driven for last-mile delivery and on the amount of emissions due to last-mile delivery, of the policy strategies. This section does thus not try to predict the future, but shows the possibilities and effects of different strategies. After the chapter Model Application, recommendations can be made for new research to fill new knowledge gaps and data sets. Research question five can finally be answered by doing so.

Next, the findings from the conceptualisation, the specification, the verification and validation and finally the model application are converted to overall findings to answer the main research questions. This step is the last step shown in figure 1.3.

2
Literature review

This chapter aims to give an overview of all relevant aspects within the scope given in section 1.2 and related to the research questions. First the e-commerce market will be described, by elaborating on the actors and the factors. Furthermore the relation with transportation is described. Secondly an overview is given on the logistic sector by describing the actors, the last-mile deliveries and the competition between logistic actors. Finally, a review is done on System Dynamics and research done on transportation using System Dynamics. These will be used in the creation of the simulation model.

2.1. E-commerce market

In this section the different types of e-commerce are discussed and their relation with transport and logistics. Firstly the e-commerce market will be discussed by demand and supply and their important influences and factors. Secondly by describing the various services in combination with their logistic characteristics.

E-commerce is the online commercial transaction between parties (Visser et al., 2014), a customer and a retailer, and more generally speaking, a demand and a supply side. Both sides are influenced by each other as described in the conventional economic theory of Marshall (1980), the demand side can only buy what is offered and the supply side reacts on the demand curve to improve its supply. The theory can be applied for e-commerce, with the online interaction as market place. This difference brings a first set of factors for the demand side. These will be discussed later in this paragraph. The different types of demand and supply determines the type of e-commerce: Business to Consumer (B2C), Business to Business (B2B) and Consumer to Consumer (C2C). Transactions made by e-commerce can concern goods and services, a service can be the purchase of flight tickets online. This report focuses on the e-commerce of goods from B2C. Goods need to be delivered to the consumer, the transportation of goods is therefore part of the service offered by the e-commerce supplier. The type of goods are quite influential for the type of transport, a large product can logically not be delivered by cargo bike and a home-delivered meal is not going to be delivered by a truck as can be imaged. The Transport Layer Model will elaborate this phenomenon in the next section. A variety of segments can be found within e-commerce for goods, like already mentioned in the Scope. All segments are incorporated in this study and thus relevant for the next section about Logistics.

2.1.1. E-commerce factors

Since a while e-commerce is increasingly growing, the use of internet is now part of daily activities along several generations and children are growing up with online shopping as common possibility. Retailers are also almost forced to offer their goods online due to competition, which on its turn makes it easier to shop online for consumers. A downward spiral is set where physical shops lose customers due to online shopping, which leads to an increase of online shopping due to the lack of physical shops. The increased familiarity with internet and online shopping, the decrease in availability of physical shops and the high competition within e-commerce are seen as the main factors for the growth of e-commerce (Allen et al., 2018). On the supply side, there are also factors influencing the growth. Due to the familiarity with internet, online shops are also improving their platform and making it easier to use e-commerce. This creates competition between e-commerce suppliers and with physical shops. Some retailers do not have a web shop, the reason is the lack of competition in that specific branch (like for low-budget retailers Action and So-Low) or the lack of profitability of having a online platform. (De Tijd, 2020)

2.1.2. E-commerce and transportation

The growth of e-commerce leads consequently also leads to a growth of freight transport and changes in the logistic sector (Burt and Sparks, 2003). The most used vehicles for this type of freight transport are delivery vans, the increase in amount of delivery vans is not equal to increase of e-commerce use the amount of vans is slightly increasing. However, the comparison in yearly amount of kilometers driven between vans used for e-commerce and vans used for other activities (private or business), is interesting. The vans used for e-commerce drive in general 50 percent more kilometers per year than the ones used for other activities (CE Delft, 2017). This can be explained by the fact that delivery vans are used continuously during the day, where as a plumber only uses it to go from one address to the other whilst the main activity in inside the house. The higher value of the indicator, amount of kilometers for delivery vans, is still no complete explanation for the small increase of delivery vans.

2.1.3. Conclusion e-commerce market

Due to several factors on both the demand and supply side, the amount of e-commerce is increasingly growing for all types of goods and services. The goods purchased with e-commerce are mostly delivered by vans. A equal increase of vans as increase of e-commerce was expected, however other research has established that this is not true. The amount of kilometers driven per year for e-commerce is 50% higher than for other activities done with vans, this can partly explain the lower increase of purchased delivery vans.

2.2. Logistics

A large component of e-commerce is the delivery of the purchases bought online, this makes it impact on logistics very important. In the previous section the various types of e-commerce services and their influence on logistics is already explained shortly. In this section the emphasis will lie on the logistic elements of e-commerce that create competition between e-commerce suppliers, like free delivery and free return shipments for example. Also different aspects of the delivery will be discussed in this section.

2.2.1. Link e-commerce logistics

As previously mentioned, e-commerce growth has impacts on logistics and transport. Burt and Sparks (2003) discusses two important distribution flows, the large number of direct deliveries to stores and the large number of small drops to homes, they mention that the latter one is not only replacement of the first one but also an addition to the first flow. This is part of the question where retailers are unsure to keep their old supply chain strategy active or to recreate a new one for e-retailing. The location of the stock, a store, depot or manufacturer, is not that clear to determine anymore. Next to this, depots for the storage of packages, located in the inner city, are moving to the suburbs due to the increasing land value, this trend of sub-urbanization of the depots makes it currently even more complex (Allen et al., 2018). The introduction of pick-up points or deliveries at another central place, like workplaces or parcellockers, can also be added to the retailers' logistic issues. Retailers operating on a large scale, can easily scale up and offer different services, but this is more complicated for small retailers. Expected is that small retailers will have to find new opportunities and that the bigger retailers will grow even more.

2.2.2. Last-mile delivery

Furthermore, e-commerce uses the concept of last-mile delivery. The difference between a plumber and last-mile delivery is already made, but within the last-mile there also variations. The last-mile delivery planning is quite complex, there are a lot of variables that contribute to the outcome of the supply chain characteristics, routing and planning: time frames, types of goods and their services required, types of vehicles, peak pressure, costs, but also the use of parcellockers or pick-up points as specified in the latter paragraph and in the Scope. The difference between the delivery of white goods and mailbox sized parcels will be used to illustrate the variations. White goods, like a washing machine, will often be installed when delivered. This requires more skills of the drivers and is also quite time-consuming. The amount of stops that they can make during a tour or day is consequently quite low. The delivery of mailbox sized parcels is in comparison less complicated for the drivers and also faster, which consequently leads to more stops per tour. In addition, the demand for white goods is in comparison with parcels lower (CE Delft, 2017), logically the distance between the households is larger in this case. To sum up, within last-mile delivery, a lot of variations can be established that all add to the complexity of delivery supply chain. Online purchases can be delivered using different traditional forms of last-mile delivery, via a Courier, via Express providers and finally with a Parcel delivery (CEP). Their main differences lie in the delivery time and in parcel type. Couriers offer a same-day delivery, using a point-to-point path. Express providers offer also a fast delivery, often on the next day or on the second day (depending on their infrastructure). The online purchases are delivered in a fixed time window. Parcel delivery consists of light-weighted parcels that are delivered the next day or on the second day. A paper from Ducret (2014) mentions that these traditional definitions are blurred nowadays, a CEP player, like DHL or UPS, often offers and combines all services.

The growth of e-commerce leads to more kilometers driven for last-mile deliveries but not for an strong increase of delivery vans. Government institutions are concerned about the negative impacts the growth might have. This leads to restrictions for last-mile deliveries with vans in city centres. The use of other types of vehicles, like cargo bikes and special mopeds, is becoming more popular as well as the use of other delivery types, like delivery at pick-up points. These new vehicle types have mostly a lower load capacity, this influences the logistic planning. Having pick-up points can also lead to other decisions made by logistic service providers, like using a van with more load capacity since everything can be dropped at once (van Duin et al., 2020)

2.2.3. Competition

The competition is aggressive in this market, retailers make the deliveries continuously more responsive to the demand of the consumers, which makes the service more expensive for the retailers (Allen et al., 2018). In addition, online retailers often incorporated the delivery costs in the prices of the product, which leads to a misconception about the overall costs (Thuiswinkel, 2020a). Consumers expect as a result zero delivery costs and the possibility of returning the bought product for free. In combination with the increasing responsiveness, fastness and reliability of deliveries. the competition is hard and retailers fight to maintain their market share. New players, like Amazon, make it even harder to survive in this competition. Amazon provides fast and cheap delivery of products as it does not use intermediary retailers and this is beneficial for consumers. Retailers can sell their products via Amazon, but Amazon becomes owner of your product and data and can consequently easily exploit you and copy your product for cheaper prices (RTL Z, 2020). This power that Amazon generates, changes the competition in these markets.

2.2.4. Conclusion logistics

The logistic sector is greatly impacted by the growth of e-commerce. The are different e-commerce segments, also discussed in the Scope, these have their own logistic characteristics. The growth of e-commerce influences these markets all differently and they also adapt differently on the changes. A white good is more complicated to drop off at a pick-up point, whilst a parcels can easily be delivered at a pick-up point for example. Due to the high competition in the logistic market, consumers have an incorrect perspective on costs of logistic services. This leads to blurred lines within the conventional forms of Courier, Express and Parcel deliveries. The normalization of next-day delivery is one of those service which lead to an incorrect perspective.

2.3. System Dynamics

This method is used in the research instead of other static methods. The reason for a dynamic method will shortly be discussed along with already existing dynamic and conceptual models that form the basis for the conceptual model made in chapter 3 & chapter 4.

2.3.1. System Dynamics in general

In 1961 Forrester developed this method to investigate the economic, business and organisational systems. This methodology is able to explain the effects of decisions made in complex systems, by illustrating the internal relations and structures and external interdependencies (Thaller et al., 2017). Feedback loops and time delays can be used to represent these dynamics. The model can be used both qualitative as quantitative, with each way their advantages and disadvantages (Table 2.1. The method was originally developed as quantitative model, but shortly after some argued that the quantitative aspect dominated the method whilst the other aspect of the method, 'system thinking' or 'qualitative system dynamics', was also valuable (Wolstenholme, 1999). Where qualitative models are quite strong in mapping structures and feedback loops, they could also be misleading in their insights, which can intentionally be used by people, or when people are inexperienced with the method. Quantitative models can illustrate behaviour of a system over time by using (emerging) non-linear and differential equations and data, however validating such models can be quite complicated and sufficient experience is needed to do so (Wolstenholme, 1999).

2.3.2. System Dynamics and transport systems

The method can be used in a variety of research fields, with transportation as one of them. Several actor groups are often involved in transport system and different interactions between factors and the actors occurs. Also, the implementation of transport policy takes time and influences the different factors at different times on different levels. Granting subsidies for electric vans for example, does not immediately result in the purchase of electric vans. Owners will first wait till they need a new vehicle until their current van is to old. Several researchers have already made models illustrating structures with transportation and logistic system, however this field of research is not the most common one for system dynamics. The reason for this phenomenon is unclear. Most of the research that is in this field, aims to understand and assess the impacts of instruments for transport policies, mostly policies concerning passenger transportation and spatial effects/developments are investigated. Models about freight transportation are in the minority and therefore only a few studies can be used for the literature review. Within these studies some have a very broad scope (regional, national, international) whilst some focus on the structures between the freight transport and the logistic choices along the supply chain (Clausen et al., 2016). Several papers discuss the applicability of system dynamics on transportation systems (Abbas and Bell, 1994; WANG et al., 2008). Both argue that transportation systems can be complex and that they often include non-linear relations, feedback loops, and delays. Three articles using System Dynamics in the transportation field are analysed to get an overview of the existing models and the knowledge gaps. These studies are also used to get inspiration for the simulation model of this research.

Aschauer et al. (2015) describes the interrelationships between logistics and transportation operations in a research paper using a system dynamics approach. They created six causal loops, shown in figure 2.1: a reinforcing loop that illustrates the logistic effect, a balancing loop for fuel costs, a balancing loop for transport emissions, another balancing loop for transportation lead time, two balancing loops that illustrate together the transport efficiency and finally two reinforcing loops that both portray rail transport.

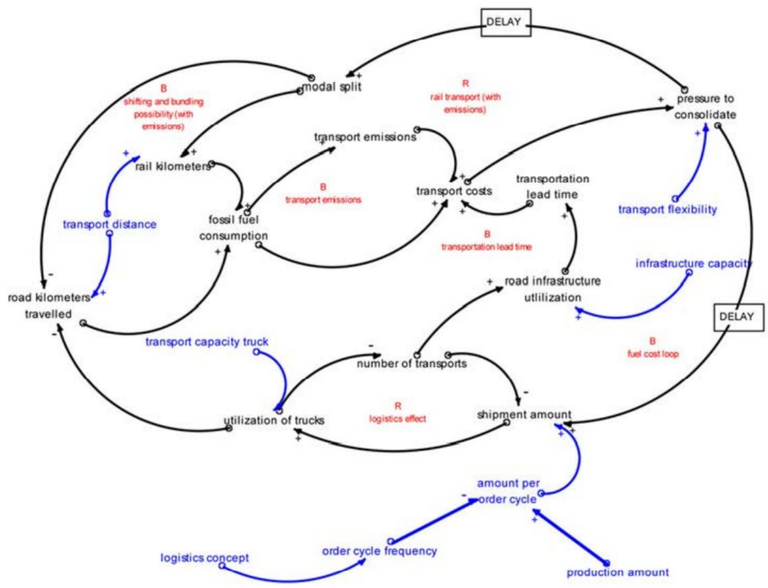

Figure 2.1: Causal loop diagram (Aschauer et al., 2015)

Interesting in this CLD is the link between *Shipment amount* and *Road kilometers travelled* (in lower half of the figure), since this link shows that an increase of the shipment amount leads to a decrease of the *Road kilometers travelled*. The increase of truck utilization leads to relative less kilometers driven in this CLD. This type of link can be used as inspiration in the simulation model development to explain the growth of e-commerce and the small increase of delivery vans. The other causal loops could also be used as basis for this research, however the model illustrates the growth of freight demand and transport flow too aggregated in the scope of this research. A model split relation is also shown in the model of Aschauer, this will not be used in the simulation model of this research. Further more they identify five parameters that are important inter-dependencies between logistic strategies and transport operations: transport flexibility, order frequency, truck load capacity, costs and modal shift. The research is focused on the road and rail transport and is present on a higher aggregation level as infrastructure utilization, part of the traffic market in the Transport Layer Model, is a element of their system. The levels of this research are lower (freight market and transport market), see Figure 3.2 for an illustration of the Transport Layer Model. Nonetheless these five parameters and the model construction can still be used as inspiration to form a certain basis for the simulation model.

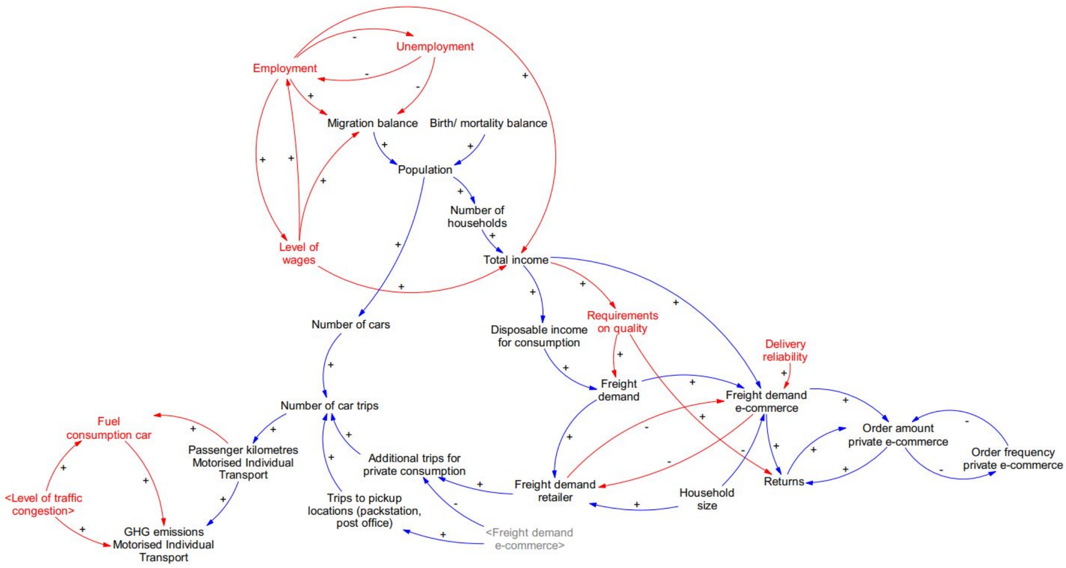

Figure 2.2: Causal loop diagram (Thaller et al., 2017)

Another research, a research from Thaller et al. (2017), focuses on the CEP market in urban areas and presents a model that combines transport and land use. The link between growing freight demand and transport is investigated, however the model also includes passenger transport (Figure 2.2) as these are still present. Both flows are necessary to calculate the effect of freight demand (physical and e-commerce) on transportation. The research illustrates a causal loop including tour characteristics, this loop is quite relevant in this research, since this is part of the complexity of last-mile deliveries, as mentioned in the Logistic paragraph. The loop including tour characteristics will be used in the development of the simulation model. The link with passenger transport will not be used in the simulation model, as the research focusses on the impact on the amount of kilometers driven for last-mile delivery by conventional delivery vans.

Both transport models are illustrated with an aggregated view, however transport can be quite discrete and less aggregated than shown in these figures. Supply chains are also part of transport systems, as mentioned in paragraph 2.2.2. A model describing a supply chain is therefore also needed to describe the link between capacity needed to deliver all packages and the available logistic capacity.

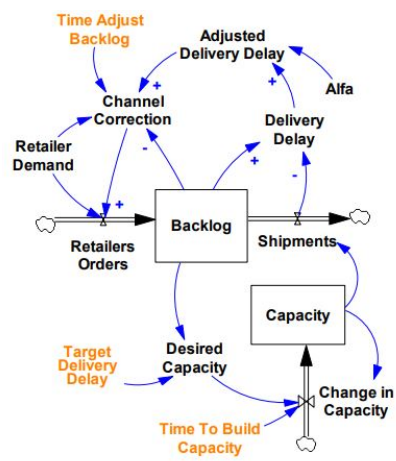

Figure 2.3: Supplier-retailer system in SD (Goncalves and Arango, 2010)

Goncalves and Arango described in 2010 in a very simple model the relation between a retailer and a supplier, shown in Figure 2.3. This is an interesting model as this research attempts to model the link between the packages ordered with e-commerce and the delivery of these packages. The CLD shows a level of capacity that is determined by the desired capacity, based on the backlog of the retailer. The dynamics in this system corrects continuously the capacity available, this also occurs for the capacity package deliveries. These dynamics are also used in the development of the simulation model to complement the relations found in the two other researches.

2.3.3. System Dynamics & This Research

This research aims to illustrate the structures between the e-commerce demand and the logistic supply chain. Already existing SD models for transportation illustrate the interdependencies between the freight market and logistics, as just mentioned, and can be used as basis for this model. However the scope of this research lies on the effect of the e-commerce growth on the logistic supply chain, this link is not researched extensively in the research discussed. A model illustrating the structures between e-commerce and logistics will fill in the research gap. Policy instruments influencing logistic characteristics within the supply chain are included to understand the effects of these decisions. System Dynamics has it strengths and weaknesses, in table 2.1 an overview is given.

Table 2.1: Strengths and weaknesses System Dynamics

Subject	Strengths	Weaknesses
Conceptualisation	Integration & accumulation of variables possible	Heterogeneous behaviour
	Feedback between variables	Stochastic
	Visual communication	
Specification	Data-poor	Only equations can be used
Verification & Validation	Sensitivity analysis	Verification on model purpose

As mentioned, its power to conceptualise integration's and feedback is one of the reasons to choose for System Dynamics. Next to its strength of being useful as communication tool and the fact that its data-poor. Using System Dynamics is also valuable since little literature is available on freight systems using System Dynamics. The Kennisinstituut voor Mobiliteitsbeleid mostly works with linear models, the usage of System Dynamics in this research could also show the possibilities of System Dynamics for other further research.

2.3.4. Conclusion System Dynamics

System dynamics is a method to illustrate and quantify the structures between variables and subsystems. Dynamic behaviour of variables can be researched and their impact can be quantified. System Dynamics can also be used to model freight transportation systems, however this is not a common research field. Research so far focus on different freight markets or simulate the growth of e-commerce in the CEP market including the effect on passenger transport, but excluding the effect on the logistic supply chain, as discussed previously. The combination of dynamic transportation system and supply chains will be analysed the relation between e-commerce growth and the amount of kilometers driven for last-mile delivery. Via this indicator, the impact of e-commerce on the environment and mobility will be made in this research.

3
Conceptual Model

In this chapter the method is shortly recapped and the base of the conceptual model are described. The conceptual model is build on several theories and models, the transport layer model and the supply and demand model, both will be explained. Actors involved, will also be described. The chapter will end with an illustration of the system boundaries using a Bull's eye diagram. The simulation model in the next chapter is scoped on by these boundaries.

As mentioned before, System Dynamics (SD) are used to build the conceptual model and the simulation model. A problem analysis is done before hand to conceive enough knowledge and sense of the problem, the conceptualization phase in Figure System Dynamics methodology (based on Slinger, 2014). By structuring the problem, relevant components and links are revealed, which are necessary for the SD model. Mostly literature is used for the problem analysis, and system thinking is used to create an overview of all perspectives and subsystems relevant to the problem. A Bull's eye diagram is shown at the end of this chapter to show the boundaries of the conceptualization and will in the next phase, the specification, indicate the scope of the simulation model.

3.1. Problem Analysis

From the ordering of products till the delivery at home, different theories are involved that explain the relations within this sector. Buying products online is done on a e-commerce platform offered by an e-commerce supplier (like Bol.com). The delivery of the ordered product is done by a logistic service provider, this supplier can also be the same actor as the e-commerce supplier. The combination of these two players, are the e-commerce market since logistic characters are of such importance for the buyers. The relation between the consumers and the suppliers of e-commerce can be explained by an economic theory, the Supply and Demand theory. The relations within the logistic sector can be explained with the Transport Layer Model. In the following paragraphs, both theories are explained and used to create the conceptual model.

3.1.1. Supply & Demand Theory

In microeconomics, one of the most important principles is the one about supply and demand of services and goods. This principle explains why and how transactions are made between parties, the consumer and the producer. The consumer is interested in a good or service of a producer and is willing to pay a certain price for that good or service. One important variable for this transaction is the price of the good or service, the price is in general variable to the demand and supply of the good or service. The scarcer the good or service, the higher the value of that good or service and vice versa. Scarcity can arise due to a higher demand than supply, or due to a lower supply than demand (Marshall, 1980). This leads to competition and finally to price equilibrium's within specialized markets, like the price of bread or potatoes. The prices of goods and services online is likewise regulated by supply and demand, and the supply and demand theory can consequently explain the relations between consumers and e-commerce suppliers.

The consumers are the ones that use e-commerce to do their purchases (demand) and producers are the ones that provide online shopping (supply), and in this market specifically the suppliers are also responsible for the delivery of the purchases. The demand side consists thus of the amount of purchases, the desired level of services, and since delivery is part of the purchase, the desired service level of deliveries. As mentioned in the Literature review, the competition concerning last-mile deliveries is high. Free (return)shipments, next day delivery and track and trace are all part of the services that consumers expect and are all part of this hard competition. The supply side consist on its turn of the amount of e-commerce service providers (e.g. Bol.com) and of the level of service they provide. The delivery of the purchases, specifically packages, can be done by the supply side themselves but a third party can also be contracted, a logistic service provider, like PostNL.

An important observation in this triangle of actors, is the indirect relation between the consumer and the logistic provider. The logistic service provider delivers the product, but this actor has no contract with the consumer, only with the e-commerce supplier. The foundation of the conceptual model, based on the three actors and their relations, is shown in Figure 3.1, the actors are displayed in blue rectangles and their relations are represented by the arrows pointed in the direction of the relation.

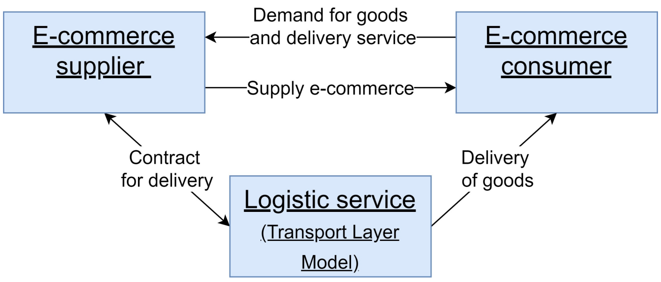

Figure 3.1: Foundation of the conceptual model

3.1.2. Transport Layer Model

In Figure 3.1 the lower box shows the logistic service provider, this actor is responsible for the transportation of the purchases, in this case thus the parcels. For the transportation of parcels, goods or persons, several types of transport services are used, which are simplified defined as followed in hierarchical order: an infrastructure is used for vehicles drive on and these vehicles transport goods. In the Transport Layer Model (TLM) these different transport services are represented in three layers, illustrated in Figure 3.2, the traffic market, the transport market and finally the freight market (van Binsbergen and Visser, 2001). Between these layers there are interactions and reactions, the behaviour of the actors within the layers is determined by the characteristics of each layer, like price and quality of products or services (KiM, 2020). For example, in a city without any train connection, goods will not arrive by train, and large parcels, like washing machines, will probably not be delivered by bike. The TLM is applicable on the delivery of parcels bought online. The road, the amount and location of DC's and their capacity can all be seen as part of the infrastructure (traffic market) in this case. The vehicles (transport market) used in the e-commerce market are mainly delivery vans, but also special vans and cargo bikes are increasingly used for deliveries. Finally the components that form the movement of goods (freight market), the delivery of goods in this case, are the types of delivery, the distribution of the stops, the amount of stops, etc.

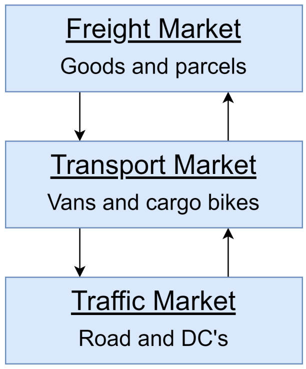

Figure 3.2: Transport Layer Model (based on (KiM, 2020; van Binsbergen and Visser, 2001))

3.1.3. Aggregated Conceptual Model

Figure 3.1 showed the direct link between e-commerce and the use of logistic service for the transportation of the ordered parcels. This transportation has on its turn an effect on the environment and on mobility, as generally known. A concrete example: the more online purchases done, the more delivery capacity is needed, the more delivery vans are used, the more km's are driven with more emissions in total as a consequence (if fuel-based). However this base model is not a closed system in reality, additional elements need to be added: Factors, Developments and Government Instruments (Figure 3.3).

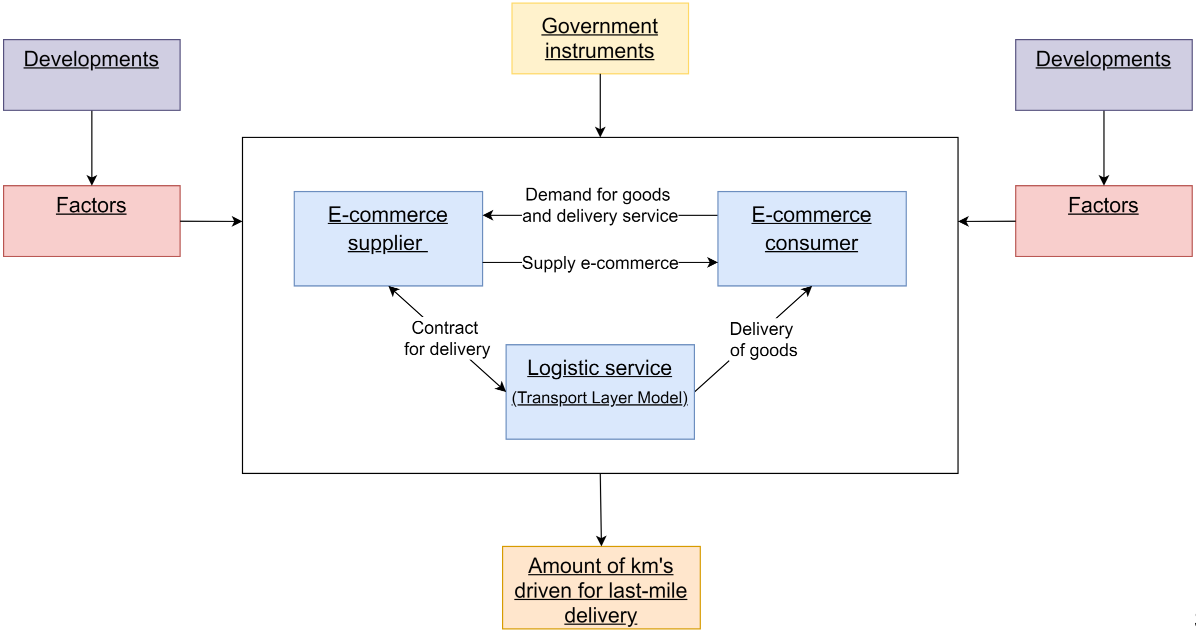

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Figure 3.3: Simplification of overall system illustrating the relation of the e-commerce market and the logistic sector

The underlying factors influence the components of the base model, the red boxes. Due to an increasing familiarity with internet, more people tend to shop online for example. Developments also influence the system, but via these factors. The development COVID-19 had as consequence that physical shops were closed, causing an increase in the demand for online shopping. These developments will thus eventually impact the environment and mobility via the transportation system. The negative impacts should be monitored and limited, if needed, by the government. The government can intervene with different instruments on various aspects within the base model, such as subsidies for electrical vans. This component, consisting instruments, is shown in yellow in the figure. In this figure, only an overview of the different components is given. Every box can be split in many characteristics and elements, this extensive version is shown in Figure 3.4.

The demand of e-commerce is defined as the amount of online purchases done by consumers (only B2C). Between e-commerce suppliers different services can be offered, but physical shops are also still part of the competition, a package arriving too late, can lead to a physical purchase next time or to a change of e-commerce supplier. Important elements influencing the demand are the type of delivery service (delivery time, drop-off location and delivery tariff) and possibilities and characteristics of return shipments (possibility available, drop-off location and return tariff). The desired level of these elements are characteristics of the demand side, shown on the right part of the figure. The type and level of the delivery service provided to the demand side, is set by the e-commerce supplier, shown on the left side of the figure. The two components, supply and demand, are linked by two arrows, one indicating the e-commerce service provided to the consumers (lower arrow) and one indicating the purchase of goods online (upper arrow).

Between the supply and demand side, the logistic service is shown. These four vertical block chains are based on the Transport Layer Model illustrated previous paragraph. The four block chains are explained from left to right, from supply side to demand side. In figure B.1, in the Appendix B, only the four block chains are shown. The first set of blocks, named Online Infrastructure, represents the contract between the e-commerce supplier and the logistic service provider. Agreements about prices, quantities and services are decided in the contract. This component is not in the scope of this research and extensive understanding of this component is not needed.

The second set, the logistic infrastructure, is representation of the traffic market. The public road is the main infrastructure the vans drive on, as well as the logistic infrastructure build by the logistic service provider, like the location and amount of distribution centres (DC's). The government regulates a part of this infrastructure, like time windows for city accessibility and the allowed road speed. Contracts with suppliers decided how much capacity is needed and where, however not for every new contract a new DC is build. Co-operations are engaged in regions that already have an infrastructure.

The infrastructure determines the vehicles that can be used, in the transport market, and are most efficient to use. As mentioned, 25% of the deliveries fails to be successfully delivered the first time. The package can be delivered at the neighbors house, pick-up point near by or even brought back to the DC for a second attempt the next day. The latter one causes more spaced to be used and consequently more kilometers to be driven. The first-time failed delivery policy can thus partly determine the total amount of last-mile kilometers to be driven for e-commerce.

The third set is the transport market. In this market the use and type of vehicle are determined, the vehicles interesting for this research are the conventional diesel vans, electric vans, special moped vans (e.g. vans from Picnic) and cargo bikes. They all provide the transportation of B2C last-mile delivery of packages in urban and rural areas. Vehicle restrictions in the inner city can lead to the use of special moped vans or cargo bikes, the need of high capacity can on its turn lead to the use of bigger conventional vans.

The latter example shows the influence of the fourth set, freight market or the delivery set, on transport market. The fourth set is the most extensive set and less researched set since it is mostly part of the logistic supply directed by the logistic service provider, like routing and delivery windows. A differentiation can be made within this set of blocks, elements that have direct effect on the consumer and elements that are not notable for the consumer. The type of delivery, delivery at home or pick-up point, has direct effect on the consumer. The same can be sad for the size of the delivery time slot, the time of the delivery time slot and the delivery time itself (from ordering till delivery). Via the e-commerce supplier, the preferred delivery characteristics are already known (delivery type and delivery time) and can influence the behaviour of the freight market. The other elements, like the amount of stops made per day by a delivery van, have less influence on the consumer. The load-capacity of a vehicle, influences the amount of packages that be in loaded in a van and thus that can be delivered in one tour (loaded at DC till returning empty at DC), which influences the amount of stops per tour. The demand side also influences the transport market directly, the location of the consumer can be in a zone with vehicle restrictions and thus lead to another vehicle choice. The growth of e-commerce demand can mean more demand per consumer and can also mean more consumers in total, both are directly related to the distribution of consumers in the fourth set. The distribution of consumers is denser than before, which can be translated to shorter distances between consumers and thus shorter distances between the stops made per tour. An increase of demand per consumer can be translated to more packages per consumer and thus more packages delivered per stop. This can also be linked to the element *Amount of stops per tour*. This shows that a growth of e-commerce leads to logistic benefits, as shorter distances and less stops are more efficient.

3.1.4. E-commerce Segments

In the Scope an overview was given of the different segments within e-commerce (Table 1.1) based on Boer et al. (2017). These segments can be found horizontally in the four set of blocks. Every segments has its own characteristics for the blocks in figure 3.4. The first one, Parcels Express, incorporates the parcels and high value express mail, like fashion, household items, electronics and books. This market is highly influences by the growth of e-commerce, and only a few players, like PostNL, are active and have a high drop density with a hub-and-spoke network. The second segment is called the Small retailer, both for food as for non-food products. This segment is mostly active for B2B deliveries, like the delivery of fresh food at restaurants or other Just-in-Time deliveries. The deliveries are often smaller, non-scheduled and service at the delivery location is included. The retailer has mostly its own regional point-to-point network. This market is also influenced by e-commerce. A player like Coolblue is partly part of this segment, since part of their business is the delivery of white goods with the installation of these goods. The drop density is lower and the installation takes a lot of time and less stops can be made during the day in this segment. E-grocery is the next segment, this segment is specialized in the delivery of food and food-boxes, like Albert Heijn home delivery or Hello Fresh food-boxes. The vans used for these deliveries are often temperature controlled and have mostly a flexible strategy with a local hub-and-spoke network. A few years ago, this market was almost non-existing. Furthermore, the Wholesale food deliveries consists of large volumes delivered at specific time slots. Only 18% of the deliveries is done by vans, trucks are mainly used in this segment. This segment is not influenced by e-commerce. The last segment, the return shipments, are not an official segment mentioned in the Scope. However extra vans are needed for those shipments and they have different routes and characteristics than the Parcels Express deliveries.

3.1.5. Actors

As can be seen in the figure, there are three key actor groups in the figure, the e-commerce consumer, the e-commerce supplier and the logistic service provider. Every actor has its own choices and is influenced by other actors or factors. Next to these three actors, a fourth stakeholder should be considered, the government. As mentioned in the Introduction, there are several impacts that are of concern for the government. In the following figure the choices made per actor are illustrated. The choices are based on literature, the supply and demand theory and on components from the TLM. The choices made per component influences other components and eventually also the amount of km's driven for last-mile delivery and therefore impact the environment and mobility.

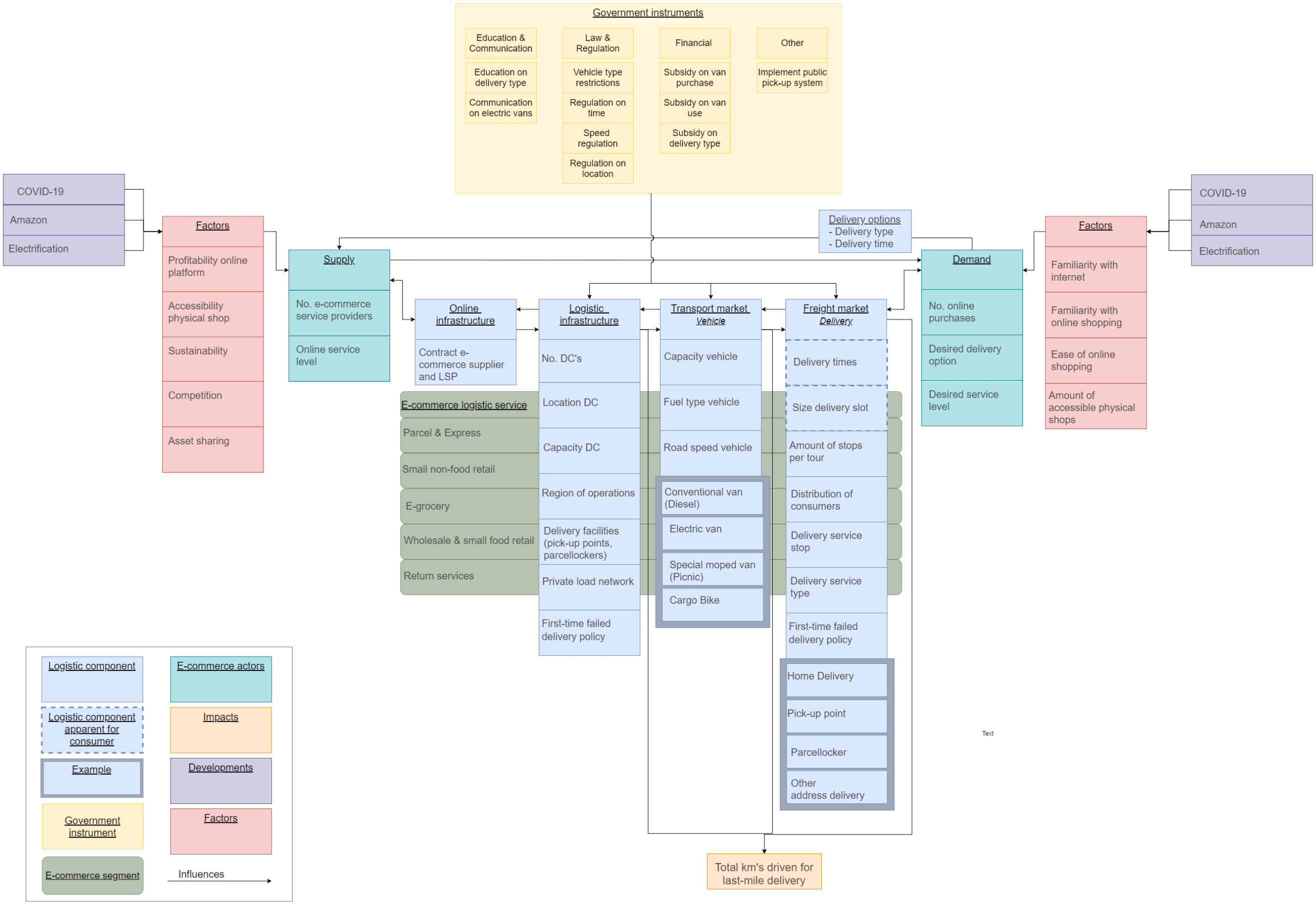


Figure 3.4: Conceptual model

3.1.6. Government Instruments

Another element of the model is the potential influence of the government instruments via policy levers, on the freight market, in Figure 3.3 these instruments are represented by a yellow box named 'Government instruments'. A policy is formed by an instrument used to adapt certain levers, which leads to a reaction of the relevant parties. Subsidies are for example an instrument that adapts the price (lever), which leads to a change of purchasing patterns (policy). These definitions are based on documents published by the Ministry of Infrastructure and KiM (Ministerie van Infrastructuur en Milieu, 2018) & (Visser and Kansen, 2018). Firstly the current policy instruments and the relevant levers are gathered to get an impression of the current situation.

Government instruments in the Netherlands are defined in categories: Education & Communication, Co-regulation, Support-creation, Dispute resolution, Transparency instruments, Financial instruments, Distancing instruments and Law & regulation. Subsidy given for the purchase of electrical vehicles is an example of a financial instrument and a national campaign like MONO, against distraction while driving, is an example of education & communication (Visser and Kansen, 2018). Policy levers are the characteristics on which the government can react. In the example of the subsidy, the type of vehicle/fuel is the policy lever. Increasing the amount of electrical vehicles (policy) can thus be done by financial aid (instrument).

The concerns of the government are in this case related to the amount of vans, due to their impact on the environment, traffic safety and traffic flow in urban areas. The policy levers corresponding to these aspects can be deducted from the problem analysis, figure 3.4. The table below (Table 3.1) shows a matrix that indicates which government instrument can be used for the various policy levers. The instruments influence the system all in their own way, the complexity of the system makes is difficult to determine how they will influence the in the Chapter Model Application the effect of each

Table 3.1: Government instruments and Policy levers

Policy levers	**Categories of government instruments**		
	Financial	Law & Regulation	Education & Communication
Vehicle	X	X	
Fuel	X	X	X
Speed		X	
Delivery location	X	X	X
Examples	Subsidies on type of vehicle or type of delivery, or taxes	Emission requirements, speed restrictions, ToD regulation, vehicle size restrictions	Awareness pollution rate vans, information benefits pick-up points or parcellockers

3.1.7. Problem Analysis Assumptions

Due to several factors, an increasing familiarity with internet and online shopping, an increasing ease of online shopping and the amount of available physical shops in the area, the demand for e-commerce is growing. E-commerce suppliers can on the other hand also offer more, having an online shop is becoming more profitable and there is also quite some competition in this field. Both the demand and supply of e-commerce are growing, which leads to a higher need of more logistic capacity. Many links between the demand and supply of e-commerce influence the behaviour of the logistic sector, but also vice versa. In the literature review the changes in the last-mile delivery sector are described, the amount of vans for e-commerce is not growing at the same speed as the demand of e-commerce is. The amount of kilometers for e-commerce is however much higher for vans used for e-commerce than for other goals. This would suggest a link between the growth of e-commerce and some sort of economies of scale in the logistic sector. The conceptual model shows more elements and relations that are necessary to simulate the link between e-commerce growth and logistic efficiency. In order to simulate this relationship in the given time period, a specification needs thus to be made of the conceptual model presented in this chapter.

In the following figure, Figure 3.5, a bull's eye diagram is illustrated. This diagram shows which elements are needed to simulate the relationship, and on which level they are needed. The elements that are most relevant, are displayed in the inner circle *Thoroughly modelled endogenous variables*. The next circle, *Superficially modelled endogenous variables*, simulates the endogenous elements more simplistic. *Exogenous variables* are elements that influence the model, but not vice versa. Finally, some elements from the conceptual model are omitted. These are also displayed outside the circles. The *Package supply chain from supply to demand* stands for the process of the packages, starting at the entering of a DC and ending at the arrival destination. Based on this supply chain, the needed logistic capacity of the delivery system can be estimated. The distribution of consumers is an important aspect of this estimation, and therefore the size of the region of operations. If the area grows along with the growth of e-commerce, then the distribution of consumers doesn't become denser. The same size of region of operations is therefore assumed and the demographic characteristics of this area will be exogenous. Packages are mostly delivered during the day and not at night, however this aspect will not be used, only the amount of available delivery hours per day are relevant.

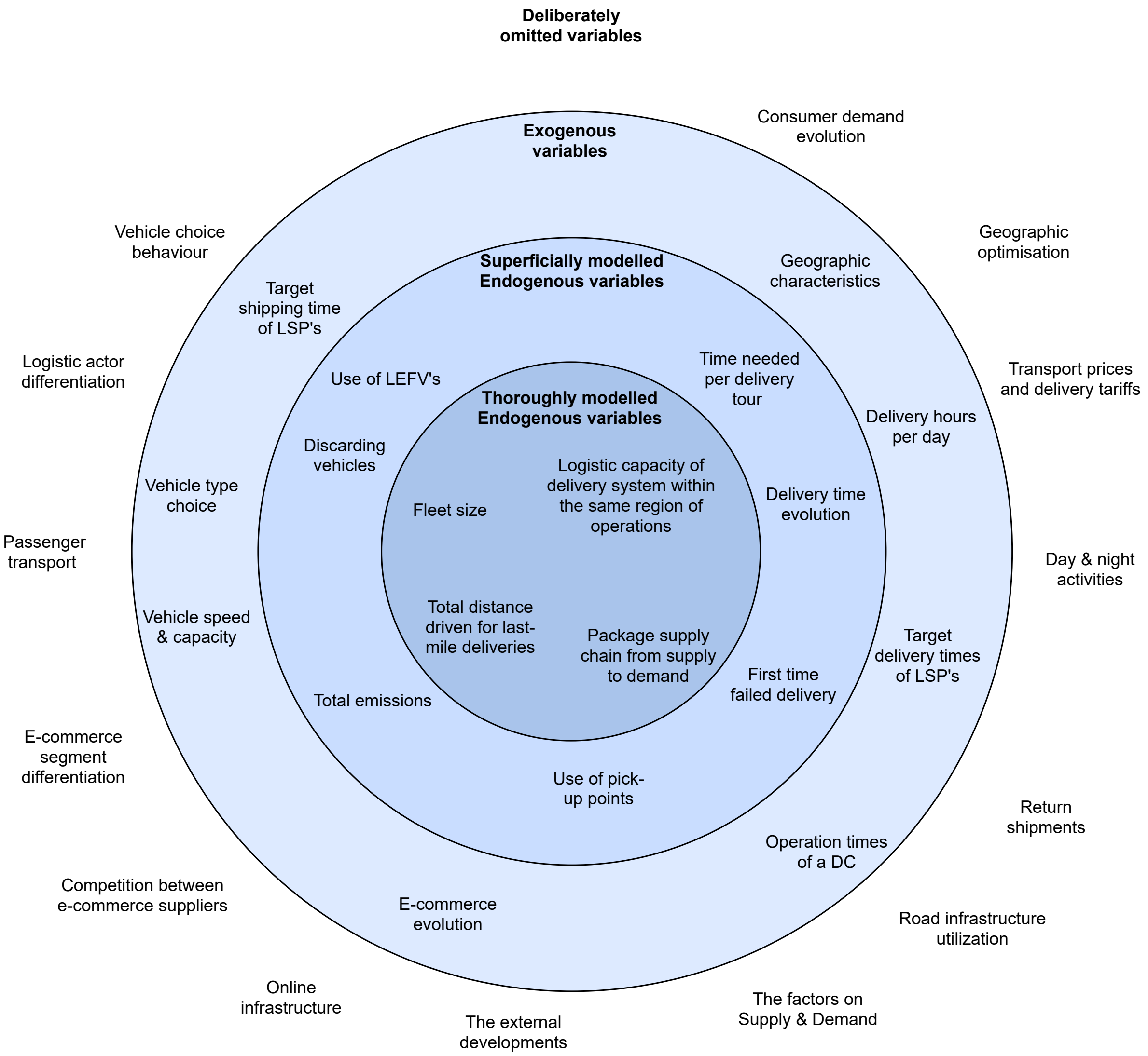


Figure 3.5: Bull's eye diagram of the scope of the simulation model

Differentiation between different LSP's, like PostNL or DHL, and between different segments will be excluded. Literature indicated that these elements can be relevant, however due to time constraints these elements are omitted. The perspective of the consumers and their reaction on the delivery service is shown in the conceptual model, but is indicated as an omitted variable in the Bull's eye diagram (*Consumer demand evolution*. Finally the developments and factors indicated in the conceptual model are also excluded in the next phase, as shown in the bottom of the figure.

4

System Dynamics Model

In the previous chapter the conceptualization of the system is made with a problem analysis and the system boundaries are shown in a Bull's eye diagram. This diagram also forms the first step towards the specification, figure 1.4, of the system to create a simulation model, which will be implemented in the software package of Ventata systems, Vensim. First a short summary of the method is given, a complete description can be found in 1.3. Based on the system boundaries, the specific objective and scope of the system dynamics model can be set in the second paragraph, followed by the assumptions. Next, the relevant relations within the system boundaries are shown in a causal loop diagram. Furthermore, the system dynamics (SD) model is discussed by sub-model and its performance indicators. Finally, the verification and validation of the SD model is discussed.

Quantitative System Dynamics is used to simulate the relations established in the Literature review and in the Conceptual Model. In this research the use of System Dynamics is appropriate method to model these flow structures and evaluate the accumulations and delays.In the Conceptual Model many relations were discussed, and boundaries were established for the SD model. These are used to describe the models purpose and to set the scope of the model, a SD model includes as much perspectives as possible but the model is a simplified and closed system eventually. Model questions are specifically defined for the SD model and a Causal Loop Diagram (CLD) is used to show the relevant relations within the model boundaries, which is part of the specification phase. After the system description, the model is developed and then verified and validated. The verification and validation consist of several tests, the models purpose is important for some of these tests. Eventually the results of the model are used to answer the model and research questions (see section Methodology).

4.1. Objective & Scope

The goal of the research is to investigate the impact of e-commerce on the amount of kilometers driven for last-mile deliveries, with a view to make conclusions about the impact on the environment and traffic safety. The literature and problem analysis have established that the growth of e-commerce demand does not lead to an equal growth of the transportation used for e-commerce. A simplification of the conceptual model is used to develop a model that can simulate this relation, since simulating all the relations in the conceptual model is too ambitious to simulate in the given time period. A second goal of the research is to analyse government instruments and their effect on the amount *Kilometers driven for last-mile delivery*. No concrete categories of government instruments are included in the simulation model, the policy levers are the link with the SD model via the model parameters, illustrated in Appendix D. The questions that the model should answer are the following:

- What is the effect of e-commerce growth on the amount of kilometers driven for last-mile delivery?
- What is the effect of policy levers on the amount of kilometers driven for last-mile delivery?
- What is the effect of the described policy strategies on the amount of km's driven for last-mile delivery?
- Which policy strategy can optimize the last-mile distance driven per package?

4.1.1. Assumptions

A previously mentioned, the simulation is a simplification of the conceptual model and its system boundaries are shown in the Bull's eye diagram (Figure 3.5). Setting system boundaries, also means that assumptions are made to make it a closed system. In the next paragraph, the assumptions for the simulation model are described.

- The model displays the delivery of packages ordered via online shopping in urban areas in days for 15 years (= 5500 days).
- The effect of passenger transport is not simulated in the model.
- The characteristics of the urban areas can be compared with average sized cities. In the Variables in simulation model, the specific sizes and sources are shown.
- No differentiation is made in logistic suppliers, all packages are delivered by one fictional supplier.
  - This leads to a distance between stops around 300 to 500 meters in the urban areas.
  - No ownership over the vans is defined.
  - Only one type of vehicle can be simulated in the model, by changing the values of the vehicle characteristics, different vehicles can be simulated.
  - Generally, packages are sorted at night and shipped during the day, this time aspect is not modelled.
- Only B2C e-commerce is modelled.
- The demand of e-commerce is set as the total demand of packages per year in the Netherlands.
- The demand is exogenous and will first grow with 15% per year (ACM, 2020; Roland Berger, 2017). After about a decade this grow will be less steep and eventually stay constant. This is s-shaped growth is inspired on the Product Life Cycle theory (Scheuing, 1969), as e-commerce will not outgrow the total demand of goods.
- E-commerce growth is defined as more customers and more demand per customer.
- Based on the demand of customers and on urban logistic characteristics, the amount of vans needed is calculated.
- Not all packages are delivered, a rate determines the amount of packages that fails to be delivered. This rate, 25%, is based on a report from Topsector Logistiek (Bezit en gebruikers bestelbussen).
- The growth of demand leads to direct logistic advantages:
  - The distance between stops is reduced since more packages are delivered in the same area, since more packages per customer are delivered and more customers per area are served.
  - The time needed to deliver a package at a stop is reduced. More packages are delivered at one stop whilst the same time is needed, therefore the time used per package is shorter.
  - Since more packages are delivered per customer and thus per stop, less stops are needed per tour.
- Prices are not incorporated as well as a link with the e-commerce demand.
- Based on the the amount of kilometers driven for last-mile deliveries, the total amount emissions is monitored. This indicator can also monitor traffic safety and mobility, since the area stays the same.

This list of assumptions can in the next step be used to establish the relevant relations necessary to describe the effect of e-commerce growth on the amount of kilometers driven for last-mile delivery. These links are discussed in the next paragraph, using a causal loop diagram.

4.2. Causal Relations

The problem analysis shows that a lot of components are relevant in this complex system and all these components impact each other in one way. The SD model simulates the most relevant causal relations and the exogenous variables on these relations, a specification of the conceptual model is needed to define these structures. A Causal Loop Diagram (CLD) is used to do so. CLDs can illustrate very clearly the different components and the relations between these components. The variables in a CLD are linked by causal links and can show the possible behaviour of the system. One can identify feedback loops, once the CLD is completed. Feedback loops are often essential in the behaviour of the system as a whole. It is important to identify them and describe them correctly in order to represent the system right. Next to feedback loops, the visualization of the different relations effecting one variable can help to understand the behaviour of that variable (Sterman, 2000). The CLD is based on the problem analysis, however not all elements mentioned in the problem analysis are part of the CLD. Only the most important links found in the problem analysis are further researched in the CLD, in this case the impact of e-commerce growth on the amount of kilometers driven for last-mile deliveries. The relations in the CLD are further researched and quantified in a simulation model.

4.2.1. Causal Loop Diagram

The relations found in the problem analysis are displayed in the following CLD, in figure 4.1. The Bull's eye diagram has set the boundaries of the CLD. Links between variables in the CLD are shown with arrows pointed in the direction of the relation. Variables can have a positive relation, which means that an increase of variable A leads to an increase of variable B. Variables can also have a negative relation, this means that an increase of variable A leads to a decrease of variable B. The sign on the arrow (+ or -) indicates if the relations is positive (+) or negative (-). A third sign on the arrow, ||, indicates that there is a delay in the relation. Feedback loops are indicated by an circle arrow in the corresponding direction and the type of loop. There are Balancing or negative feedback loops (B) and Reinforcing or positive feedback loops (R). A balancing feedback loop indicates balancing behaviour, which means that every change has a counter reaction in the opposite direction. In a reinforcing loop, a change in one direction leads to more change in the same direction (Sterman, 2000). The arrows in this CLD are also color coded for the purpose of explanation. The blue arrows display the simplified supply chain of the delivery of packages, the red arrows display the effect of e-commerce growth on the logistic operations behind the delivery of the packages. The black arrows complement the blue and red arrows. All variables are black except one orange variable, this variable is the main indicator, *the amount of kilometers driven for last-mile delivery*.

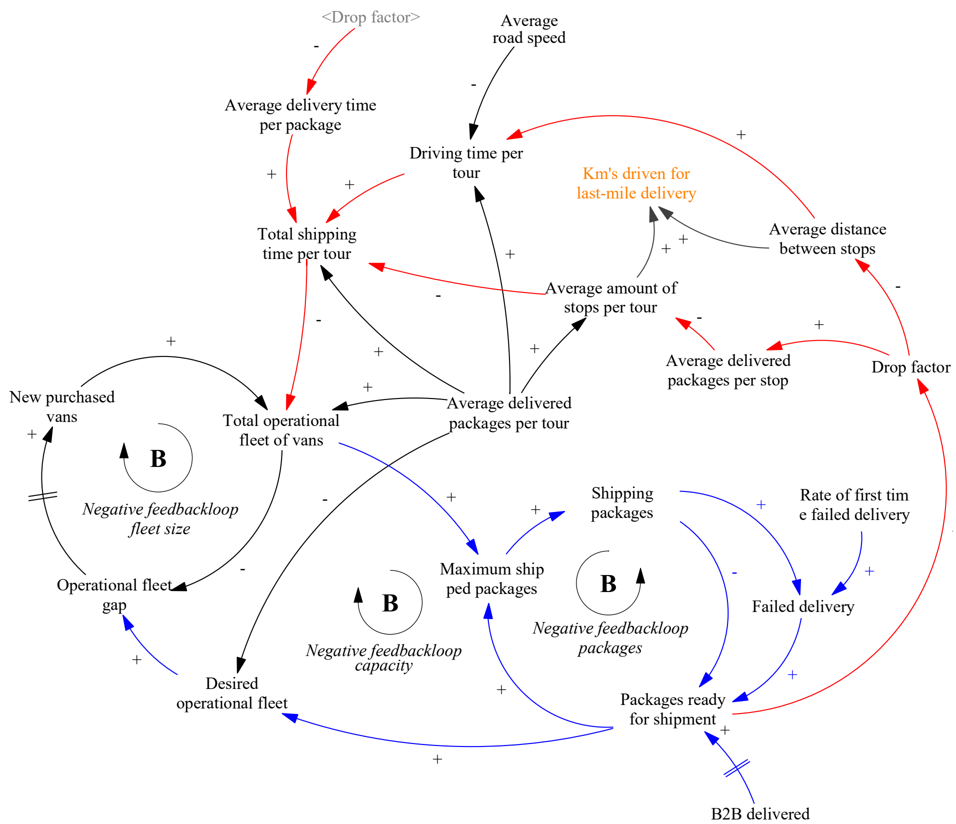


Figure 4.1: Causal loop diagram showing the relation of e-commerce demand and the amount of kilometers driven for last-mile delivery

The *B2B delivered packages* variable represents the demand for e-commerce, if this variable increases in value, like it does currently, the amount of *Packages ready for shipment* will also increase, which leads to more *Desired operational fleet*. The more capacity is needed in comparison to what is available, the bigger the *Operational fleet gap* is. This brings us to the first feedback loop, *Negative feedback loop fleet size*. This loop illustrates that the bigger the *Operational fleet gap*, the more *New purchased vans* there are, which leads to more *Total operational fleet of vans* and thus a smaller *Operational fleet gap*. In the link from *Operational fleet gap* to *New purchased vans* a delay is found. Purchasing new vans is a big investment and takes time, which causes the delay.

An increase of *Total operational fleet of vans* will lead to more *Maximum shipped packages*.

This variable also increases with an increase of *Packages ready for shipment* as one can not ship more packages than are physical available. The amount of *Shipping packages* increases with an increase of *Maximum shipped packages* and decreases the *Packages ready for shipment*, which creates the second and third feedback loop of this CLD. The most right feedback loop, *Negative feedback loop packages*, shows that an increase of e-commerce and thus the amount packages in a DC(*Packages ready for shipment*), leads to more packages that can be shipped (*Maximum shipped packages*)and thus packages that are shipped (*Shipping packages*). The more packages that are shipped, the less packages there are in the DC (*Packages ready for shipment*). Not all packages are successfully delivered in the first try, *Failed delivery*, and have to go back to the DC for a second try, which increase the *Packages ready for shipment*. This rate is currently around 25% *Rate of first time failed delivery*. The first two loops combined create the third feedback loop, also a balancing feedback loop: *Negative feedback loop capacity*. This final loop displays that the more packages are ready for shipment, the more transport capacity is created (*Total operational fleet of vans*), which leads to more shipments (*Shipping packages*). This first series of blue links in combination with the *Negative feedback loop fleet size*, is based on the Supplier-retailer system in SD from Goncalves (2.3) and on the the CLD of Aschauer (2.1). These blue links, represent the 'Package supply chain from supply to demand' in the inner circle of the Bull's eye diagram and will be the first sub-system in the SD model. The second sub-system in the SD model will be the *Negative feedback loop of fleet size*, and is called 'Fleet size' in the Bull's eye diagram.

The next series of links, the red arrows, is based on the CLD made by Thaller et al. (2017) that illustrates the causal relations between different tour characteristics. These represent the 'Logistic capacity of the delivery system within the same region of operations' in the Bull's eye diagram and will be the third sub-system in the SD model. The growth of *Packages ready for shipment* leads to an increase of the *Drop factor*. The *Drop factor* is the amount of packages or stops per kilometer. In the problem analysis the link between e-commerce growth and this so-called drop factor was established by assuming that the area stays the same. This *Drop factor* influences three variables, the *Average delivered packages per stop*, the *Average distance between stops* and the *Average delivery time per package* (in the upper left corner of the figure). As mentioned, an increase of e-commerce demand can mean more customers but also more orders per customer. The latter one is represented by the variable *Average delivered packages per stop*, the first one is represented by the variable *Average distance between stops*. The *Average delivered packages per stop* has a negative effect on the *Average amount of stops per tour*, since the more packages are delivered at once, the less stops are needed (when the amount of packages in a van stays equal, *Average delivered packages per tour*). A decrease of the *Amount of stops per tour* means a decrease of the time needed to deliver all packages (*Total shipping time per tour*), again in combination with an equal amount of *Average delivered packages per tour*. A decrease of the *Average distance between stops* leads to less *Driving time per tour*, based on an equal amount of packages and the same *Average road speed*. The less *Driving time per tour* is needed, the less *Total shipping time per tour is needed*. Two relations, started at *Drop factor*, show that an increase of e-commerce growth lead to less *Total shipping time per tour*. The third effect of the *Drop factor* is via the *Average deliver time per package*. During a stop, the postmen gets out of his vans, checks the delivery, takes out the needed package and rings the bell to deliver the package. When more packages are delivered per stop, the only thing that changes is taking out the packages, which doesn't take a lot of time. This means that instead of X amount of minutes for one stop, the amount of minutes is split over two packages. This statement is of course based on a simplified reality, but it shows that there is a negative relation between the *Drop factor* and the *Average delivery time per package*. Which also leads to a decrease of the *Total shipping time per tour*. The *Total shipping time per tour* means that a van can make more tours in a day, and thus deliver more packages in a day. A decrease of the *Total shipping time per tour* leads consequently to more *Total operational fleet of vans*. This bring us back to an increase of the amount of shipped packages, the (*Maximum shipped packages*).

The last variable, *Km's driven for last-mile delivery*, is the indicator of the amount of kilometers driven for last-mile delivery. The *Km's driven for last-mile delivery* will still increase due to the growth of e-commerce, but probably less steep due to the effect of the *Drop factor* on the *Average amount of stops per tour* and the *Average distance between stops*.

The demand from consumers is exogenous represented by the *B2B delivered packages* and the supply of packages is represented by *Shipping packages*. However this link doesn't influence the demand from the consumers in this closed system, as is the case in the Supply and Demand theory.

This closed system is mostly active in the freight market and the transport market from the TLM. The *Negative feedback loop packages* belongs in the freight market and the *Negative feedback loop fleet size* in the transport market. The red arrows, the links between tour characteristics, belong also in the freight market. The traffic market from the TLM is thus not represented in this CLD and will also not be part of the SD model.

4.3. Specifications System Dynamics Model

The CLD presented in the previous paragraph forms the basis of the SD model specified in this paragraph. In a CLD only links and variables are shown, a SD model has a more extensive set-up. The relations and variables are modelled with auxiliary variables, constants, rates, flows and stocks. Accumulation and integration in a simulation model can be modelled with a stock-flow structure. Stocks can be compared with a bath tub, an inflow creates volume in the tub and an outflow can reduce this volume. The stock is thus the integral of the inflow minus the outflow, or the accumulation of the inflow minus the outflow. Every stock has a value at the beginning of the simulation, the initial value. This value can be zero when the height of the accumulation of the stock is important, but the value can also be higher than zero when the changes within the accumulation are important. Only flows can change the state of a stock, and these should be targeted when the state of the stock should be changed. In the next figure a basic stock-flow diagram shown to illustrate the different components in Vensim.

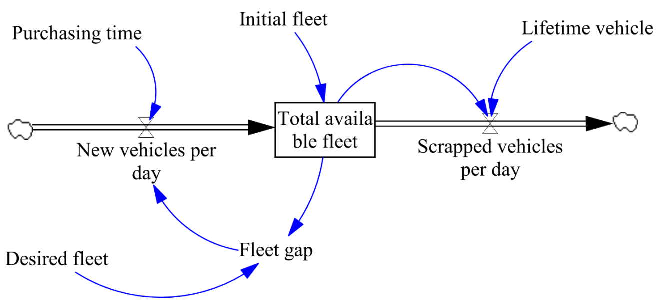


Figure 4.2: Basic stock flow diagram from van (van Daalen et al., 2011)

The unit for time is Days with Euler as integration type. Euler is chosen as integration type due to the use of some built-in functions. A small step size (0.03215) is chosen to make the model more accurate, the results are saved for every time step (van Daalen et al., 2011). The model simulates the mid to long term, 5500 days (15 years), starting at time zero. The simulation model is divided in multiple sub models, the Package flow, the Logistic capacity and the Fleet size. In section 2, the main literature is discussed that was used as inspiration for the relations in this SD model. Also data is needed for the quantification of the relations. The Centraal Bureau voor de Statistiek (CBS) provided data about the size of the e-commerce market (CBS, 2020b) as well as data about logistic characteristics, like the amount of packages per delivery tour, provided by mr. Paul Ras from CBS and via CE Delft (2017). Appendix C displays a table including all variables with their the type (exogenous constant, endogenous auxiliary or endogenous level), their (initial) value and their source. Finally, an SD expert, Dr. F. d'Hont, guided the set up and the construction of the SD model.

4.3.1. Package Flow

This flow is a simple model of a flow of packages going trough several stages, from arriving at the DC till being shipped by a vehicle. This supply chain structure is based on Supplier-retailer system in SD (Goncalves and Arango, 2010). The inflow, packages per day, is external and based on the current demand. The growth of the demand is calculated separately and is first equal to a yearly growth of 15% but this growth is not forever. The total demand of goods increases only a little over the years, the online demand of goods can never be more than the total demand of goods (CBS, 2020a). Therefore a s-shaped line of growth is expected for the demand of e-commerce, this flow structure is based on L.A. Martin (1996) and shown in Figure 4.3. The stocks are the accumulated packages in that stage. The output of the third box, *Packages ready for shipments*, is calculated using the value of the amount of

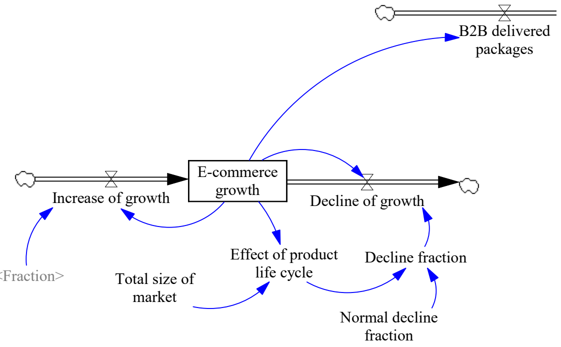


Figure 4.3: E-commerce growth (based on L.A. Martin (1996))

packages in the DC and the amount of packages that can be shipped with the available vehicles. There can not be more packages shipped than the amount of packages in the DC, but also not more than the amount of packages that can be delivered based on the amount of vehicles available. Once the packages are shipped, a part of the packages is delivered successfully, but a part of the packages failed to be delivered and will return back to the DC. No differentiation is made between the packages that are shipped for the first or second (and more) time.A part of the shipped packages will be returned by the consumers for a variety of reasons, these flow of packages is not simulated but only the amount of packages is calculated using a stock. This value is calculated to display the large amount of packages that is return in the Netherlands.

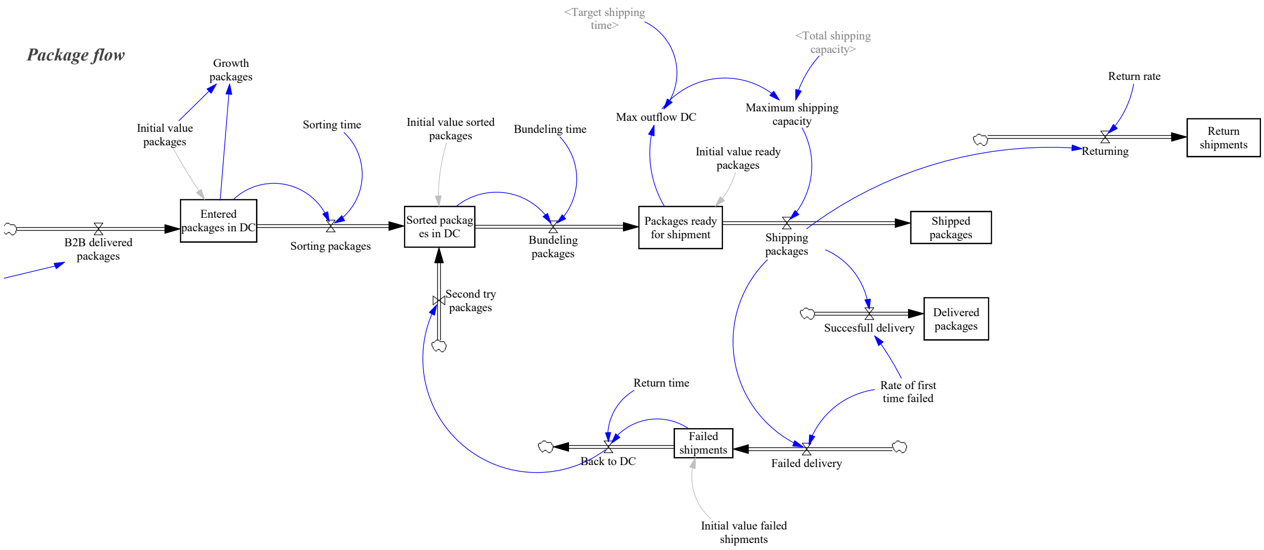


Figure 4.4: Package flow simulated in Vensim

In this first sub model, the value of the amount of packages and the *Rate of first time failed* is based on data CBS (2020a), ACM (2020) & CE Delft (2017), the processing times, like *Sorting time*, are estimations. In Appendix C the functions of all variables can be found and their value.

4.3.2. Logistic Capacity

A lot of variables influence the *Total shipping capacity*, packages per day, as can be seen in Figure 4.5. There is only one stock in this sub model, since all variables are auxiliaries and are not accumulations or integration's. These links are therefore mostly linear, which makes this sub system more an extensive calculation that is part of a simulation and not a simulation on itself. The values of the variables are based on data from CBS and other literature, see Appendix C. The *Total shipping capacity* is the output of this sub model and is based on the amount of *Tours per day* and the amount of *Operational fleet of vans*, calculated in the third sub model. The amount of *Tours per day* is modelled as a stock due to its less variable nature. Generally the amount of tours made in a day is planned ahead and does not change daily. The *max amount of tours per day* is estimated with the *Time per tour* and the *Effective daily delivery hours*. The difference between the current *Tours per day* and the *Max amount of tours per day* is used to plan more or less tours. In this stock flow diagram the input and output are one flow as the change is calculated in every time step. Change can have a positive value (inflow) or a negative value (outflow). The *Time per tour* is calculated by adding the *Total package delivery time per tour*, the time needed only to deliver the packages, and the *Total driving time per tour*, the time needed only to drive the tour.

Three variables are influenced by the growth of the demand simulated in the *Package flow*, *The package delivery time*, *The average delivered packages per stop* and *The distance between stops*, as established earlier in the CLD.

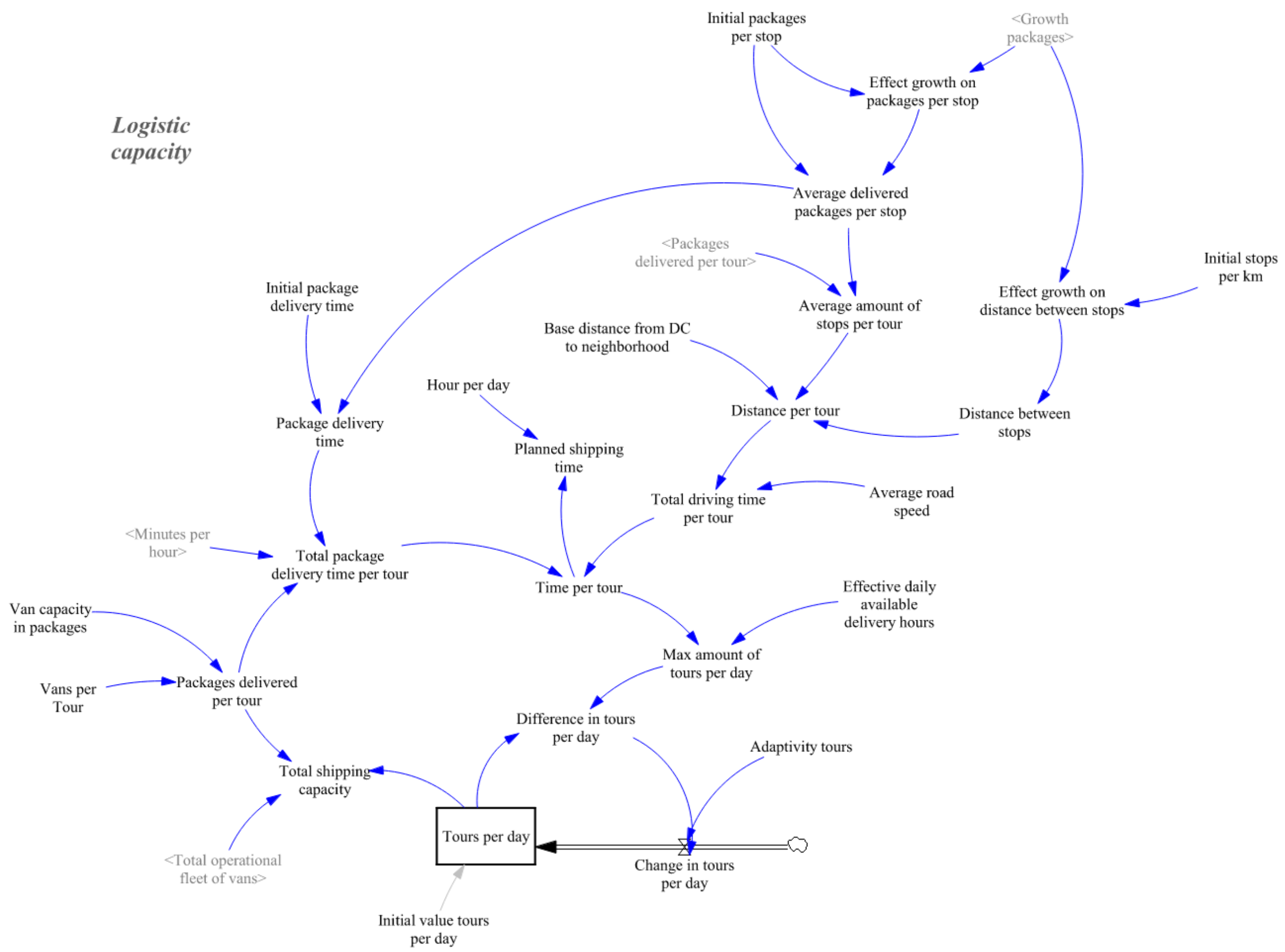


Figure 4.5: Logistic capacity simulated in Vensim

The value of most external variables is based on data about an average urban area, Peters.2012, Schonewille (2015), CE Delft (2017) and the received CBS Data.

4.3.3. Fleet Size

The final sub model (4.6) computes the amount of vehicles needed to deliver all packages in the *Package flow*. This is again based on the structure from Supplier-retailer system in SD (Goncalves and Arango, 2010). Based on the amount of packages in the DC, *Packages ready for shipment*, the amount of *Packages delivered per tour* and the amount of *Tours per day*, the *Desired fleet size* can be estimated. The amount of *Packages delivered per tour* is based on the amount of packages that fit in a van. Using the *Desired fleet size* and the *Target shipping time* the *Desired operational fleet* size can be calculated. The CLD showed a feedback loop for the fleet capacity, this feedback loop is also computed in this simulation model. The *Operational fleet gap* indicates whether new vehicles need to be purchased or not. Vehicles that are already planned to be bought, *Planned new vehicles*, are also included in this calculation. The variable, *Accepted operational fleet gap*, is used to create a threshold and is set on 10%, *Accepted margin for fleet gap*, of the *Total operational fleet of vehicles*. Only if this threshold is passed, new vehicles are set in the planning to be bought, *Vehicles needed*. After a while, the vehicles are discarded, this is the only outflow of the fleet stock, *Total operational fleet of vans*. This stock counts the total available vans in the system.

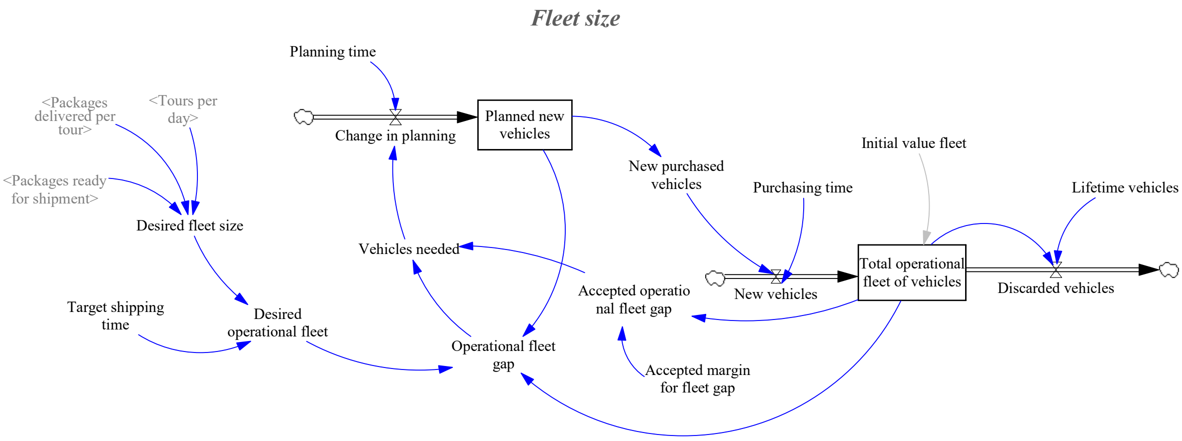


Figure 4.6: Fleet size simulated in Vensim

4.4. Key Performance Indicators

In order to be able to evaluate the model results, the most important indicators, the Key Performance Indicators (KPI's), should be chosen and defined 4.1. The research aims to analyze the impacts of the e-commerce growth on the amount of transport kilometers for last-mile. The daily amount of kilometers for last-mile deliveries will logically be evaluated, the total amount of emissions for last-mile delivery and the amount of kilometers driven per package to evaluate the efficiency of the deliveries. The total shipping capacity is also set as an indicator to evaluate possible changes in shipping capacity, and the last indicator is the amount of operational vehicles. The latter indicator is a stock and thus an integration. Accumulation and integration's in the model can indicate behavioural changes in capacity levels, the fleet size will therefore also be evaluated. All indicators are shown in the table below, Table 4.1. In the Chapter Model Application an analysis of the behaviour of the KPI's is done.

Table 4.1: Overview of Key Performance Indicators

Indicator	Unit	Initial Value	Source	Source code Vensim
Total daily kilometers	Km/ Day	1200000	CBS data & CE Delft (2017)	Daily successful kilometers + Daily extra due failure kilometers
Distance per package	Km/ Package	1.25	CBS data	INTEG (Change in distance per package)
Total operational fleet of vehicles	Van	20000	CE Delft (2017)	INTEG (New vehicles - Discarded vehicles, Initial value fleet)
Total shipping capacity	Package/ Day	1000000	N.A.	Packages delivered per tour * Tours per day * Total operational fleet of vehicles
Total emissions by last-mile delivery	CO2	0	N.A.	INTEG (Daily last-mile emissions + Extra CO2)

The last column of the table shows the calculations of the indicators. In most equations internal variables are used. The indicator *Distance per package* is calculated by variables within the *Logistic capacity* sub system, thus mostly driven by external variables. The *Distance per Tour* is partly influenced by the *E-commerce growth*, which makes it still a useful indicator to estimate the magnitude of the effect of e-commerce growth. This brings us to the importance of the values of the external variables. In the table 4.2 the values and sources of the main external variables are shown. Enough data was present on the growth of e-commerce and the amount of vehicles used and kilometers driven for last-mile delivery in general. These values were either linked to general e-commerce transportation by delivery vans or to specific B2C e-commerce. However, data sets that distinguish logistics differences in e-commerce segments were less common. The *Packages per stop*, the *Stops per km* and the *Van capacity in packages*, the *Package delivery time* can vary a lot for different e-commerce segments, as discussed in the Scope and Conceptual Model. In the next section Verification & Validation, the bandwidth of these and two other important parameters are therefore discussed. The extensive list of all external variables is shown in Appendix C.

Table 4.2: Values and sources of main external variables

External parameter	**Unit**	**Initial Value**	**Source**
Average road speed	Km/ Hour	25	Peters (2012)
Base distance from DC to neighbourhood	Km/(Tour*Van)	30	Expert
Effective daily available delivery hours	Hour/ Van/ Day	6	N.A.
Fraction	1/ Day	0,0003872	ACM (2020)
Initial package delivery time	Minute/Package	4	Schonewille (2015)
Initial packages per stop	Package/Stop	1.3	CBS data
Initial stops per km	Stop/ Km	2	CBS data
Lifetime van	Day	3000	CE Delft (2017)
(unmanned) Pick-up point effect on rate	Dmnl	0,2	ACM (2020)
Purchasing time	Day	90	N.A.
Return rate	Dmnl	0,4	Thuiswinkel (2020b)
Target shipping time	Day	0,85	N.A.
Van capacity in packages	Package/ Van	40	CE Delft (2017)
Yearly amount of delivery days	Day/ Year	310	CE Delft (2017)

4.5. Verification & Validation

In the verification phase, several tests can be conducted on the model to assess whether the model contains the correct structures. A verified and validated model can be used to draw conclusions about the system within the system boundaries simulated. The model is tested against its model purpose for the validation of an SD model (J. Forrester and P.M. Senge, 1980), this was described in the Objective & Scope section of this chapter. The KPI's are used to shown the results of the verification and validation.

4.5.1. Verification

Forrester & Senge proposed several tests in 1980 that are crucial for the verification of the SD model, these include the dimensional-consistency test, the structural-verification test, the parameter- verification test, the extreme-condition test and lastly the boundary-adequacy test. An overview of all outcomes is given in Appendix E, the most relevant information is given below.

The first check, the dimensional-consistency test, is done continuously during the model build-up. The test checks whether the dimensions of the variables in the same function are consistent, this shows the mathematical correctness of the structures. The software package used to model, Vensim, has a tool that checks the units and will show any errors. This test can also reveal faulty structures. Since this test is done continuously, no major errors were found during the verification at the end. This means that the mathematical structures are complete and no variables are missing in the equation, within the set system boundaries.

In the second test, the time horizon is checked. In the model setup a time horizon of 15 years is chosen, however a longer time horizon should also be checked to make sure that long term behaviour isn't much different. As can be seen in Figure 4.7, the behaviour of the e-commerce growth changes after 15 years and equilibrium is found after 12000 days. The behaviour of the KPI's will therefore be evaluated for 50 years (about 18000 days) instead of 15 years.

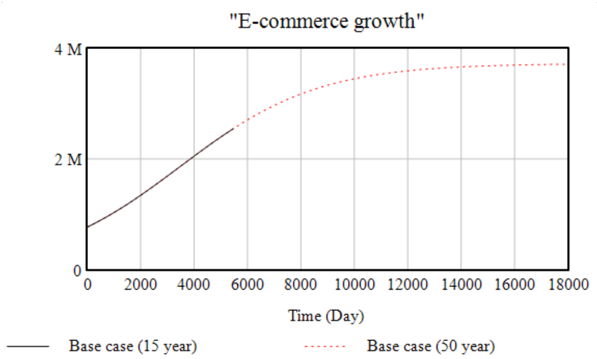


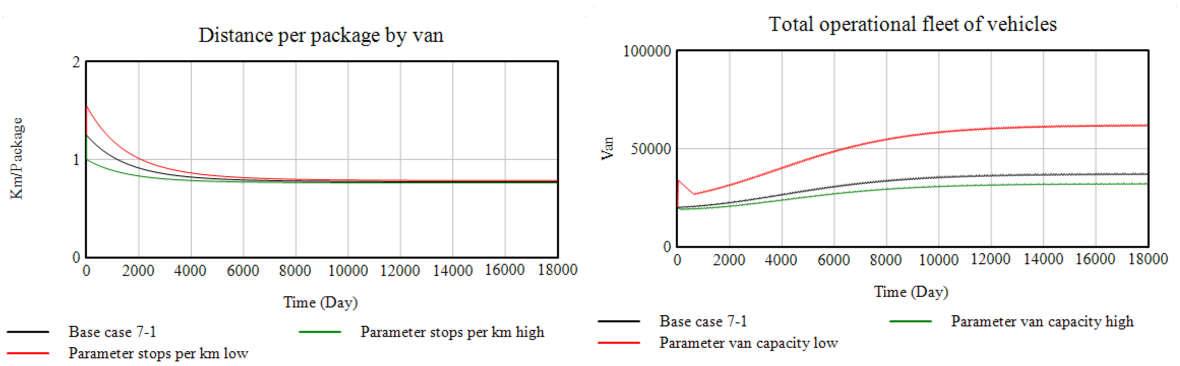
Figure 4.7: Time horizon check of the base case for 15 years and 50 years

During the structure-verification, the modelled structure is analysed and compared with the scoped system. Faulty structures in the model can cause different behavior in comparison with the observed system, the structure test helps to eliminate these structures. This is often already done during the modelling itself by the modeller. By discussing these structures continuously with other people in this case an SD expert, Floortje d'Hont, and transport experts from Delft University of Technology and the Kennisinstituut voor Mobiliteitsbeleid, the modelled structures are ensured to match the observed system. The structures in this model are simple, however they do complement the structures discussed in the literature review. The relation between e-commerce growth and the logistic capacity sub model, shows that there is indeed some kind of logistic efficiency within these system boundaries.

Table 4.3: Uncertainty table showing the bandwidth of parameters

External parameter	Unit	Initial Value	Bandwidth test	Source
Van capacity in packages	Packages/ Van	40	20-50	CBS data
Average road speed	Km/ Hour	25	18 - 32	(Peters, 2012)
E-commerce growth fraction	%/ Year	15	11.5 - 18.5	(ACM, 2020; Roland Berger, 2017)
Initial stops per km	Stop/ Km	2	1.25 - 4	CBS data
Initial package delivery time	Minute/ Package	4	3 - 6	(Schonewille, 2015)

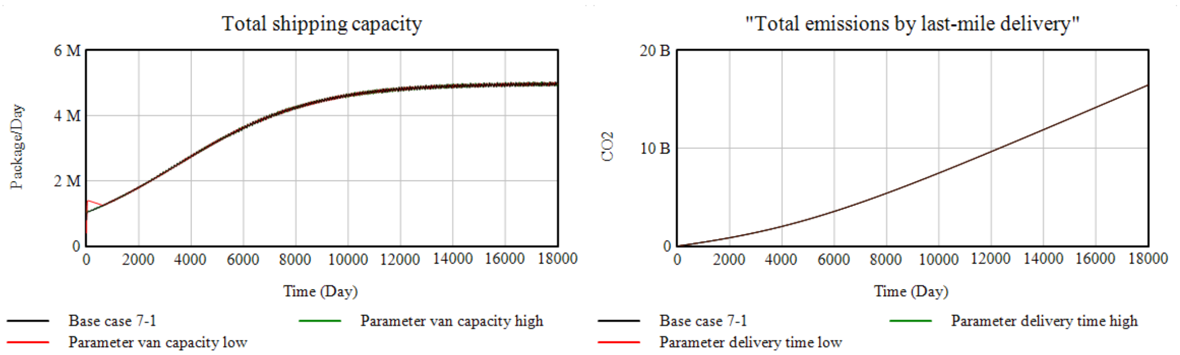
The value of the parameters is tested in the parameter-verification test. Each parameter has one value in the model itself, while a bandwidth of values is more realistic, Table 4.3. Choosing one value within the bandwidth, still gives uncertainties about the influence on the KPI's. Therefore a test is conducted to get insights in these uncertainties and thus the effect of the bandwidths on the different KPI's, which is necessary for the evaluation of the model results later on. Big differences in KPI behaviour lead to less reliable outcomes. The overall effect of e-commerce growth on the amount of kilometers driven is then more complicated to determine. Literature and available data sets may all indicate different values, based on the different definitions for example. In the test the bandwidth of values per parameter is determined and the highest and lowest value of the bandwidth are simulated. The behaviour of the output variables in the three different runs (incl. base run) are compared, shown in the following figures. Most parameters are based on data sets from CBS (see table C). Different calculations of the value of the parameters are used to include and compare the variables. In the next figures, the behaviour of some KPI's is shown to illustrate the effect of a bandwidth of values. In every figure a black function is shown, the base case, a red function, the lower bound of the bandwidth and a green function, the higher bound of the bandwidth. In Figure 4.8a the functions for *Distance per package* all start at a different level due to different values of *Initial stops per km*, but end around the same value. This means that the *Distance per package* can only decrease so much that the bandwidth of *Initial stops per km* does not influence this value. In the next figure, Figure 4.8b, the base case and higher bound case show the same behaviour only with other numerical values. The lower bound shows behavioural differences at the beginning, this is mainly caused by having the same initial value instead of adapted initial values. The difference between the lower and higher bound functions and the base case are relative to the differences in the bandwidth of the van capacity. Figure 4.9a shows that the parameter *Van capacity in packages* does not influence the *Total shipping capacity*, as expected. Again, a small disturbance is found at the beginning of the function caused by different start values. After less than 1000 days, the balance is found again. Also the *Package delivery time* does not influence the *Total emissions by last-mile delivery*, which is also valid.



(a) Parameter-test of *Initial stops per km* on the *Distance per packages*

(b) Parameter-test of *Van capacity in packages* on the *Total operational fleet of vehicles*

Figure 4.8: Parameter-test of *Distance per package* & *Total operational fleet of vans*



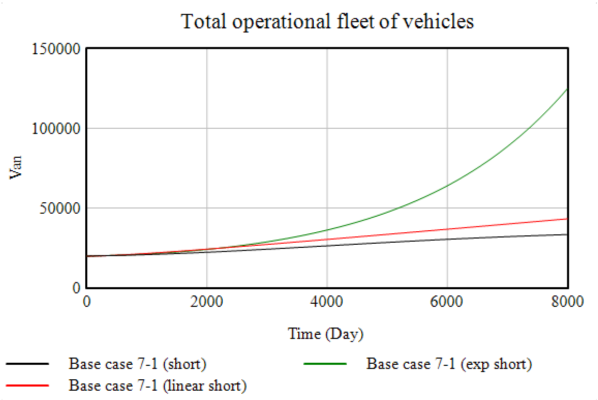
(a) Parameter-test of *Van capacity in packages* on the *Total shipping capacity*

(b) Parameter-test of *Package delivery time* on the *Total emissions by last-mile delivery*

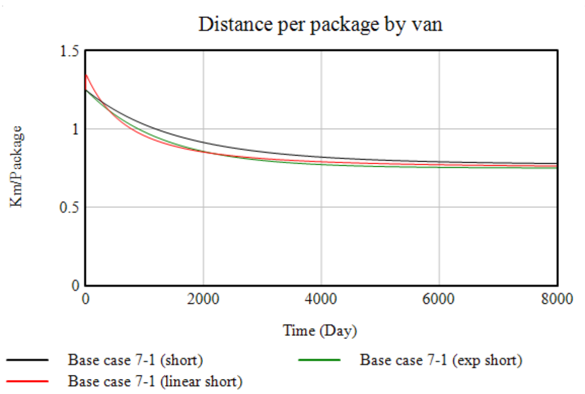
Figure 4.9: Parameter-test of *Total shipping capacity* & *Total emissions by last-mile delivery*

While determining the bandwidth of the parameters and conducting this test, insights were gained about the availability of data. Different definitions of variables, can lead to different variable units in the model. The amount of stops made by a van can for example be interpreted in many different ways. CBS uses the total amount of stops made in 3 days, whilst this model uses the amount of stops made per delivery tour. Even with the same definition, these values could also vary a lot, mainly because no differentiation is made in different e-commerce segments. This model can only draw generic conclusions, since only generic parameter values were used. This may be correct within the system boundaries, but no conclusions can be draw about specific e-commerce segments, which may be more relevant, like discussed in the Scope, Literature review and Conceptual Model.

The next test, the extreme-conditions test, can increase the confidence that one has in the model. If the model can still represent the system as expected under extreme conditions, it is more likely that the model performs well under normal conditions. Next to this argument, it is also important to know that the model perform outside the current boundaries, especially in this case since e-commerce has showed extreme growth due to the COVID-19 pandemic. If the demand of of online purchases increases extremely, one can expect to also see an extreme growth of the last-mile capacity. Such extreme values for parameters resulted in corresponding behaviour of the model, two examples of the effect of an extreme demand changes, are shown below. The red function represents the effect of linear e-commerce growth on the KPI and the green function shows the effect of exponential e-commerce growth on the KPI. In these figures, a short time horizon is chosen for a clearer illustration, due to the extreme growth of the exponential function.



(a) Extreme-test of *E-commerce growth* on the *Total operational fleet of vehicles*



(b) Extreme-test of *E-commerce growth* on the *Distance per package*

Figure 4.10: Extreme-test of *Total operational fleet of vans* & *Distance per package*

The course of the *Total operational fleet of vehicles* function, follows the course of the growth of e-commerce. The extreme changes in the *Growth of e-commerce* shows that this KPI is very sensitive for the type of growth of e-commerce. The growth of e-commerce is set as an exogenous variable and the behaviour of this variable does not lie in the model boundaries. For this research, the assumption of s-shaped growth is used and conclusions about the *Total operational fleet of vehicles* can only be based on this model boundary. The *Distance per package* is less sensitive to the e-commerce growth. Small behavioural changes can be seen between 0 and 2000 days, but eventually the functions go parallel. Their are thus differences in the behaviour of *Distance per package*, due to behavioural changes of in the *E-commerce growth*. However the three functions all seem to show asymptotic behaviour. This indicates that different courses of e-commerce growth always leads to finite logistic efficiency within these model boundaries. Conclusions about this indicator are therefore more reliable.

The boundary-adequacy test is used in different forms, in this context it is used to test the structure again. The test checks whether all relevant structures are incorporated in the model to represent the correct aggregation level and whether it is fit to represent its purpose. If not all perspectives are modelled, other behaviour than expected can occur. Hypotheses around the different feedback loops are analysed and compared with the model purpose. The purpose of the model is to find to effect of e-commerce growth on the amount of kilometers driven for last-mile delivery and to establish the effects of different policy levers and strategies on the amount of kilometers. The latter ones are related to the parameters. Within the model boundaries, different perspectives are modelled, illustrated by the different sub models. For the logistic sector, 100 % asset sharing is assumed, which is not the case in reality. The aggregation level of the *Fleet size* sub model is of a higher aggregation level than the sub model showing the package flow. Logistic supplier choices are not incorporated and no optimization within the supply chain is therefore shown. Conclusions about the height of fleet and its relation to logistic efficiency can therefore not be drawn outside these assumptions.

4.5.2. Validation

The model is build to show the effect of e-commerce growth on the amount of kilometers driven for last-mile deliveries, and to show the effect of several policy instruments. Many assumptions are made to create an environment for a closed system. A valid model means that the values and the behaviour of the model represent the modelled system, and that the model can be used to explain or to draw other conclusions about the modelled system. The model's behaviour should match the build model structure. This can be done with several test, a behaviour-reproduction test, a behaviour-anomaly test and a behaviour-sensitivity test (J. Forrester and P.M. Senge, 1980).

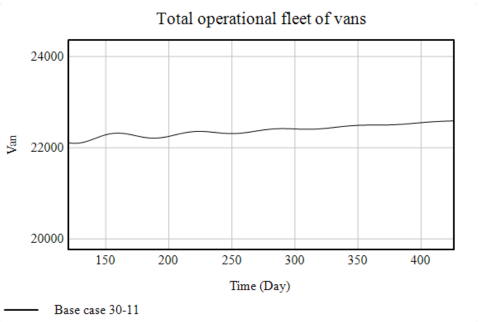
The first test, the behaviour-reproduction test, is done to compare the output behaviour of the model and the behaviour of the real system. By observing the output values produced in the model and the values of the real system, this comparison can be done. The start values of the KPI's and data from CBS and ACM (Autoriteiten Consumenten Markt) is again used. Not all values of the KPI's is available in the literature due to differences in the definition and secrecy of the private companies. The table below, Table 4.4, shows the KPI's with their start value and the value given by literature. The *Total daily distance* is lower than in literature, a possible explanation could lie in the fact that the model focuses on urban areas and that the *Distance per package* is already lower than 0.8 km/package after only 500 days (out of 18000 days). The literature value of *Distance per package* excludes the distance from the DC to the neighborhood, which explains the difference. Otherwise, the indicators are quite close to the values of the observed system, which means that numerical conclusions can be drawn within the model boundaries.

Table 4.4: Value's of KPI's at start simulation model versus literature

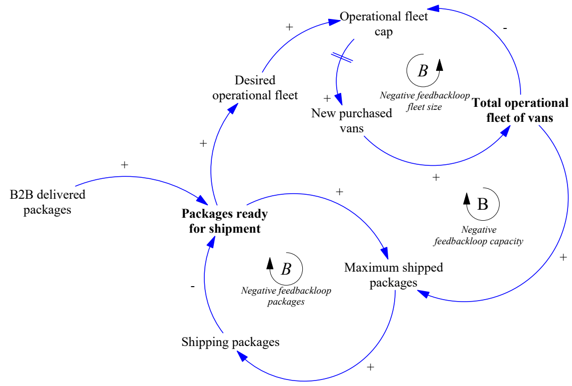
Indicator	Unit	Start Value	Literature value
Total emissions driven by last-mile delivery	CO2	0	N.A.
Total daily distance	Km/ Day	1200000	1900000
Distance per package	Km/Package	1.25	0,8 - 1.2
Total operational fleet of vans	Van	20000	15000 - 28000
Total shipping capacity	Package/ Day	800000	N.A.

The second test, the behaviour-anomaly test, helps discovering abnormalities and deviations in model assumptions, which causes conflicting behaviour with the real system. This test is done continuously during the model development. Also an expert on city logistics, dr. R. van Duin, is asked to check the assumptions and validate the corresponding model behaviour. His remarks are evaluated and implemented if possible. At the beginning of the simulation, a damped oscillation can be found in the behaviour of some indicators. Damped oscillations are found in systems were multiple stocks have to find their equilibrium in combination with negative feedback loops and delays (Kamin et al., 2002). The next figure, Figure 4.11a, shows a zoomed-in part of the behaviour of the *Total operational fleet of vehicles* with damped oscillation. In the CLD shown in figure 4.1, these negative feedback loops can be found, in the figure below only the relevant links of that CLD are shown (Figure 4.11b).

This variable is part of a negative feedback loop, shown in the Figure 4.11b and consists several stocks. Therefore the damped oscillation can be explained.



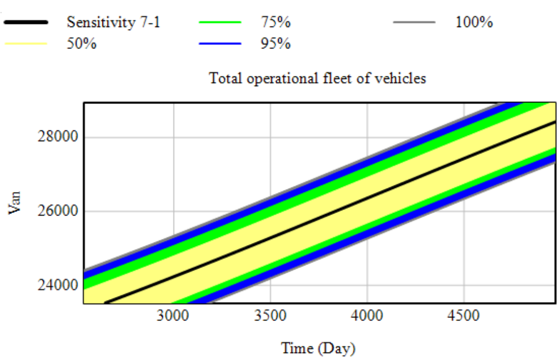
(a) Damped oscillation in the behaviour of *Total operational fleet of vans*



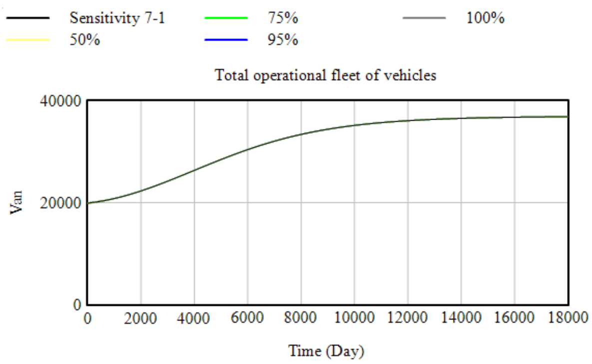
(b) CLD showing feedback loops causing damped oscillation

Figure 4.11: Explanation damped oscillation

The final and third test, the behaviour-sensitivity test, validates the influence of the parameters on the behaviour of the model. The software package used, Vensim, has a build in sensitivity test. In this test, all values of the parameters are individually changed between -10% or +10% of its initial value with a random-uniform distribution. For every combination of KPI and parameter, the outcome is analysed. The influence of the parameter on the KPI should be comparable with its influence in the real system. In the next figure, figure 4.12a, a function is shown to explain the outcome of the test. The figure shows the sensitivity test of the *Package delivery time* on the *Total operational fleet of vehicles*. The black line displays the base case, the yellow bar around it, displays 50% of all values within the new range (-10% and +10%), and so on. The amount of *Total operational fleet of vehicles* is thus sensitive to change of the *Package delivery time*, but not too much. Appendix E displays the influence of all parameters on the KPI's.



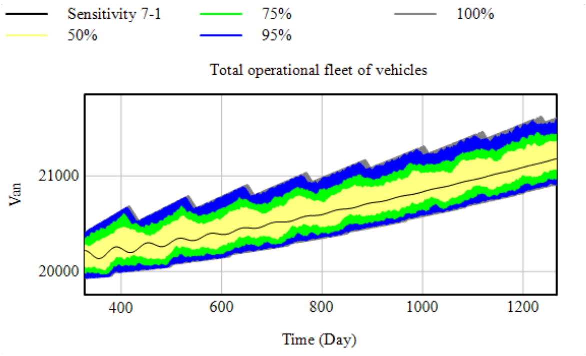
(a) Zoom-in sensitivity test on *Total operational fleet of vehicles*



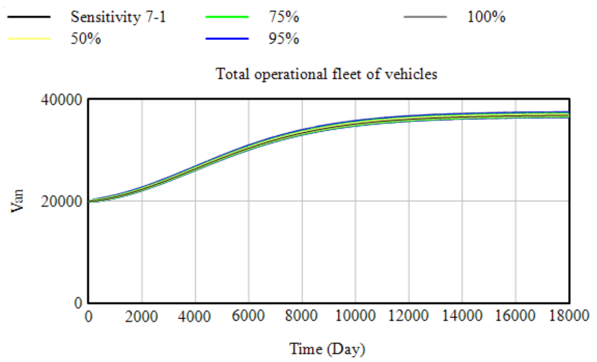
(b) Sensitivity-test of the damped oscillation, using *Purchasing time* on the *Total operational fleet size*

Figure 4.12: Sensitivity damped oscillation in behaviour *Total operational fleet size*

In the previous test, a damped oscillation was shown. This behaviour is can be explained, but it is still important to establish how sensitive this behaviour is to changes. In Figure 4.12b, the outcome of the sensitivity test of the *Total operational fleet size* is shown with *Purchasing time* as parameter, since this parameter creates the most delay. The stock is barley affected by the changing parameter, the model is thus robust enough. The sensitivity of the *Total operational fleet of vehicles* by planning time is also checked, Figure 4.13a. The bandwidth does not go straight but with a staircase pattern, which is created by a second delay. This illustrates the discrete short-term behaviour of the fleet capacity. In this case the combination of planning time and purchasing time. The whole figure, Figure 4.13b shows that the total impact is minimal on the overall behaviour and height of the function.



(a) Zoomed results of sensitivity test of planning time on *Total operational fleet of vans*



(b) Total sensitivity-test of planning time on the *Total operational fleet size*

Figure 4.13: Sensitivity planning time on *Total operational fleet size*

4.5.3. Conclusion Verification & Validation

Different verification and validation tests are conducted to assess the simulation model. The verification tests established that the model contains mathematical correct structures that can be compared with the structures of the scoped system. Changes in parameters result only in numerical changes and the model can still perform under extreme circumstances. Assumptions were made about the value of parameters, but the verification tests proved that the model behaviour is not disturbed by possible false values. The validation tests established that the model can be used to answer the model question defined at the beginning of the specification phases of the SD model. The values of some KPI's in literature are very variable, this makes it difficult to validate these values. However the behaviour seems to have no conflicting behaviour or deviations with the behaviour of the scoped system. The course of e-commerce growth does influence the course of some KPI's, like the amount of vehicles needed for last-mile delivery. This means that insights can only be used within the model boundaries. Within the boundaries, the model is robust and the output, the behaviour of the KPI's, can be used to analyze the relation of e-commerce and the amount of kilometers driven for last-mile delivery.

5
Model Application

In this chapter the results of the verified model will be evaluated. First the important indicators of the model, set in Chapter 4, are described by their behaviour in the simulation. Next, two policy strategies are described, implemented in the model and finally evaluated using scenario's.

The main input of the SD model, is the growing demand of e-commerce. Therefore the behaviour of this parameter is shown and shortly described. The demand of e-commerce, the *E-commerce growth*, grows currently around 15% per year (ACM, 2020; Roland Berger, 2017), this expected to eventually decline, see Figure 4.3. The course of the e-commerce demand is shown in Figure 5.1 and should be kept in mind when evaluating the KPI's.

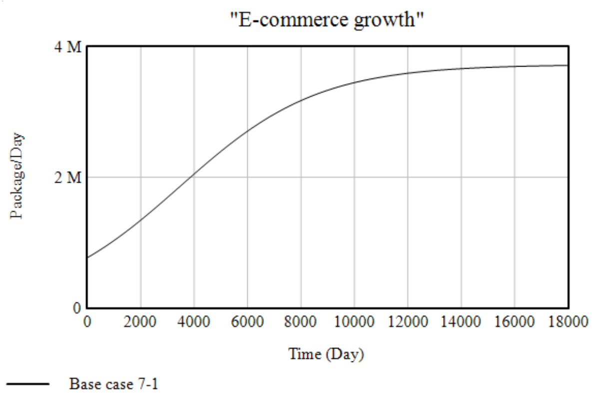


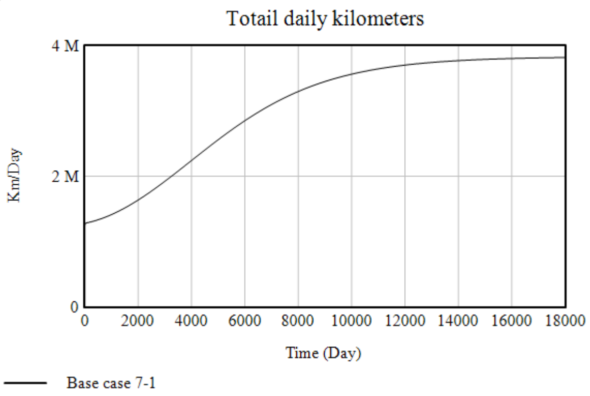
Figure 5.1: Simulation of *E-commerce growth*

5.1. Base Case

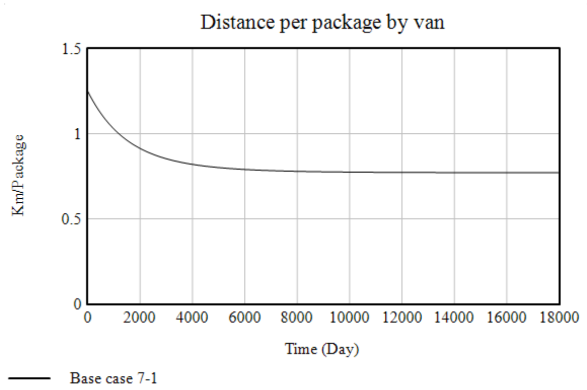
In Chapter 4, the table including the explanation of the indicators is given. In this section the behaviour shown by the indicators is discussed.

The *Total daily distance* represents, in Figure 5.2a, the daily driven distance by all operational vehicles. The function shows clearly that the amount of kilometers is linked to the behaviour of the growth of e-commerce, however the function seems to go less steep than the function of *E-commerce growth*. The second KPI, the *Distance per package* in Figure 5.2b, looks like a horizontal asymptotic at 0.75 km/package, which is possible due to the derivation in its function. This KPI indicates the logistic efficiency of the deliveries. The decrease of the *Distance per package* implies that the delivery system is optimized over time. Around 5000 days the function already shows asymptotic behaviour, while e-commerce still grows at that moment. This illustrates clearly that the e-commerce growth leads to logistic efficiency in the short term, but this efficiency growth is finite in the long term.

The *Total operational fleet of vehicles*, increases with the same course as the e-commerce growth, as expected, as more delivery capacity is desired over time. The function, shown in Figure 5.3a, is however flatter than the e-commerce growth function. Literature, CE Delft (2017), indicated already that the amount of vehicles did not grow as much as the amount of e-commerce did, this figure clarifies this observation. In the short term the amount of vehicles showed oscillation (Verification & Validation), but in the long term the amount of vehicles grows in the same pattern as the e-commerce growth. The *Total shipping capacity*, shows (Figure 5.3b) a steeper function like the one of *Total daily*

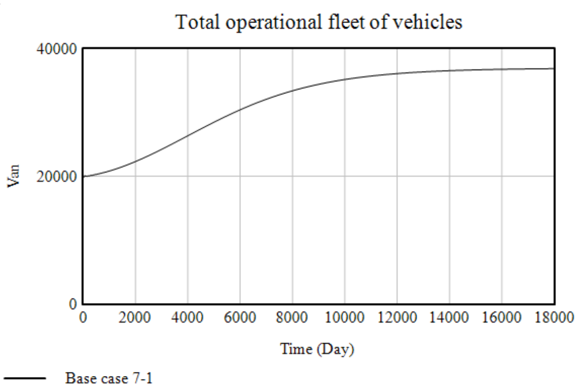


(a) Daily distance driven for last-mile delivery

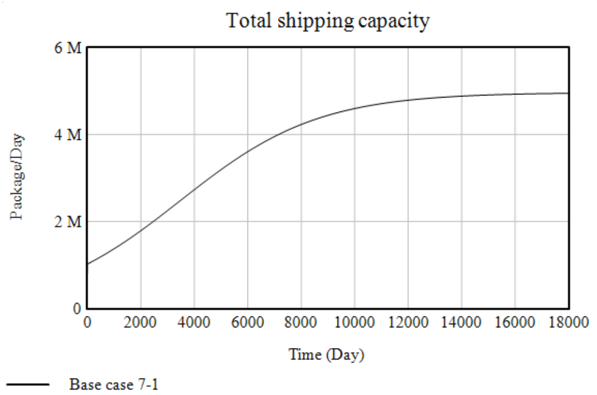


(b) Distance per package

Figure 5.2: Behaviour of *Total daily kilometers* & *Distance per package* over time



(a) Total operational fleet of vehicles



(b) Total shipping capacity

Figure 5.3: Behaviour of *Total operational fleet of vans* & *Total shipping capacity* over time

distance. When comparing the *Total shipping capacity* with the *E-commerce growth*, both with Package/ Day as unit, one can see that there is more capacity than needed. This is caused by packages that could not be delivered the first time around, which is around 25% of the deliveries.

Finally, the amount of emissions caused by delivery vans are tracked by the KPI *Total emissions by last-mile delivery*, shown in Figure 5.4. This KPI keeps increasing, as it is an accumulation of all emissions over time. A light bend around 4000 days can be found in the function, this is around the same time as the steepest section of the *E-commerce growth*, Figure 5.1. In table 5.5 the change after 50 years is shown. This rate says nothing about the development of the KPI over time, these rates are used to indicate whether the KPI will increase or decrease eventually.

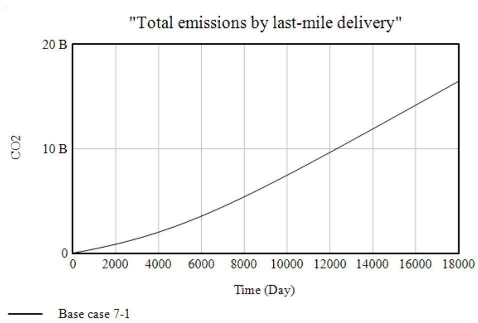


Figure 5.4: Total emissions by last-mile delivery

5.1.1. KPI's & Government Instruments

The goal of the government is to reduce negative impacts like emissions. Initiatives, like the Green Deal initiative for Zero Emission Stadslogistiek (Greendeals, 2020), are established to ensure this goal. The environment and mobility impacts, are based on the amount of kilometers driven for last-mile. Since the demand for e-commerce is an exogenous variable of the system boundaries, and increases for a while, the amount of capacity needed to deliver the packages also keeps increasing. However, the *Total daily distance* driven for last-mile deliveries and the *Distance per package* can be optimized in order to make sure that the total amount of kilometers increases less. Also the type of vehicle can lead to less emissions when non-polluting fuel or other powers are used, like electric vans or bikes.

The government has different tools and instruments to intervene, previously summarized in Table 3.1 in the Conceptual Model. In this section, the effect of policy levers on the KPI's is analysed by the SD model. System boundaries are set up for the SD model based on the conceptualisation model, shown in the Bull's eye diagram of the scope of the simulation model. Only the corresponding policy levers to these model boundaries are evaluated in this section, shown in table 5.1. This table and the effect of the individual levers on the KPI's are used to chose policy strategies.

Table 5.1: Government instruments and Policy levers specified for simulation model

Policy levers	Categories of government instruments			Parameters in simulation model
	Financial	Law & Regulation	Education & Communication	
Vehicle	X	X		*Van capacity, Average road speed, CO2/km*
Speed		X		*Average road speed*
Delivery location	X	X	X	*Average delivered packages per stop, Package delivery time, Distance between stops, Rate of first time failed deliver, Van capacity*

No concrete categories of government instruments are included in the simulation model, the policy levers are the link with the SD model via the model parameters, illustrated in Appendix D. The corresponding parameters in the SD model are shown in the right column of table 5.1. The delivery location and the vehicle type are most represented in the SD model, the policy strategies are therefore also linked to these two policy levers, further discussed in the next section.

First, the influence of every parameter, and thus policy lever, individually is analysed. The link of the parameters with the model variables is shown in Appendix D. For every parameter a sensitivity test is done on the KPI's in order to establish which parameter has most influence on the KPI's. All results are shown in Appendix E. An overview of the results in given in Table 5.2. The influence of the parameter is shown by color, green means that the corresponding parameter influence the indicator clearly and yellow indicates that the parameters only influence the indicator a little. No color means that no clear influence within this simulation model is found after the sensitivity test.

The parameters *Van capacity in packages*, *Rate of first time failed delivery* and *Average delivered packages per stop* are the three most influential parameters in the SD model. Changing these parameters can lead to less daily kilometers driven for last-mile delivery, less operational vans and eventually to less emissions. The *Average road speed* and the *Package delivery time* do influence some KPI's, however this influence does not lead to less kilometers driven for last-mile deliveries and neither for less shipping capacity. Which means that the environment and mobility will still be impacted at the same rate as without intervention. The distance between stops (*Initial stops per kilometer*) is less influential than expected, probably due to the use of a *Base distance from DC to neighbourhood*.

Table 5.2: Influence of parameters on respective KPI's

Indicator	*Daily distance driven*	*Distance per package*	*Total operational fleet of vans*	*Total shipping capacity*	*Total emissions*
Van capacity in packages					
Rate of first time failed delivery					
Average delivered packages per stop					
Initial stops per kilometer					
Average road speed					
Package delivery time					

5.2. Policy Strategies

As mentioned previously, based on the available instruments, levers and the effect of the corresponding parameters on the KPI's, strategies are formed. The *Van capacity*, the *Rate of first time failed delivery* and the *Average delivered packages per stop* are combined in the first strategy: '(unmanned) Pick-up points'. This strategy can be linked to the policy lever, delivery location. The use of (unmanned) pick-up points is a known solution and the government has indicated that municipalities could ease the implementation of these points by a standardization of licensing for these points (Ministerie van Economische Zaken en Klimaat, 2020), which is linked to Law Regulation. This could be in combination with granting subsidies for building an unmanned pick-up point, a financial instrument. Lastly, a national campaign (Education & Communication) to promote the use of pick-up points could also be started to create awareness about this delivery option among citizens. The second strategy, 'Light electric freight vehicles', researches the combined effect of *Van capacity*, *Average road speed* and *Package delivery time*. This strategy is linked to the vehicle type. Also this strategy is already known, and the government can help with an incentive scheme (Green Deal, 2019), which is part of the financial instrument. A more authoritative intervention, related to law and regulation, could be a restriction to enter an area by a conventional delivery van. This would either push LSP's to use other types of vehicles, like LEFV's or lead to more pick-up points at the border of that specific area.

The implementation of strategies needs time, and are smoothly incorporated in the current delivery system. As indicated in the Bull's eye diagram of the scope of the simulation model, the use and thus the activation or implementation of the strategies is endogenous. This means that a closed-loop policy is modelled, by using the variable 'Policy activation'. This variable is activated when the current flow of daily emissions is higher than the boundary set for the amount of daily emissions, see Figure 5.15a. The activation is equal to the ratio between the current amount of daily emissions and the boundary of daily emissions, and therefore relative to the difference between the two. The variable *Policy activation* is linked to the relevant parameters in each strategy, which influence the daily amount of emissions. This is the last step of closing the loop for the policy activation.

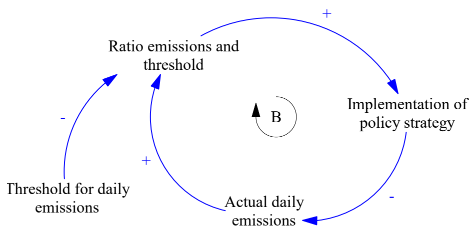


Figure 5.5: Implementation of policy strategies

5.2.1. (unmanned) Pick-up Point

In the first strategy, the influence of (unmanned) pick-up points, or so-called parcel lockers, is analysed on the KPI's shown in the first paragraph of this chapter. A pick-up point is a place where one can receive and send packages, this point is in general located in a store and human interaction with a store employee is needed to receive the right package. The packages can be picked-up during the opening hours of the store. Parcel lockers are machines that store parcels in lockers which can be used to receive and send parcels. The individual lockers in the machine are closed and opened with an unique code provided by the owner of the machine and send to the use of the locker. In this manner no human control is needed and the machines can be used 24/7. The amount of lockers per machine can vary as do the sizes of the locker, shown in the figure 5.6. Packages from the same area are delivered in a parcellocker in the same area by a postmen, the receivers can pick the package up on their own time.

(a) Parcel locker PostNL (RTL Nieuws, 12/02/2020) (b) Parcel locker DHL (Emerce, 01/19/2017)

Figure 5.6: Example (unmanned) pick-up points with different sizes

First the set-up of the (unmanned) pick-up points is determined, based on literature and the available parameters in the model, these are shown in Table 5.3. The *Policy activation* is linked to the *Rate of first time failed*, to *Distance between stops*, to the *Base distance from DC to neighborhood*, and to the *Package delivery time*. The higher the ratio, and thus the policy activation, the more the values incline to the values of pick-points, indicated in table 5.3.

Table 5.3: (unmanned) Pick-up point strategy

Variable	Value base case (delivery van)	Value pick-up point
Rate of first time failed	25%	5%
Distance between stops	500 m	0 m
Base distance from DC to neighbourhood	2x15km	2x20km
Package delivery time	4 min	1 min

The delivery man does not need to drive to all stops individually, but can deliver them all in one stop in the best situation. This decreases the *Average amount of stops per tour* needed, but also the *Distance between the stops* as defined in the model. As the delivery man can deliver all packages in a locker, a lot of time is gained by reducing the *Package delivery time* (ringing the bell, asking for a signature etc.). The availability of the receivers is also less of an issue, this leads to a decrease in the *Rate of first time failed* packages. Parcel lockers are often placed in areas without any restrictions, therefore the vans can be bigger and have more load capacity (van Duin et al., 2020). The final advantage of (unmanned) pick-up points is related to the return shipments. (unmanned) Pick-up points can be used for both receiving as sending packages. This means that the delivery man can first load all packages in the parcel locker that are returned by the consumers and than reload the parcel locker with the new packages for the receivers (Figure 5.7). The amount of empty trips is reduced by this effect, however this effect is not estimated in the SD model.

The implementation of pick-up points starts thus at the moment that the amount of daily emissions is higher than the boundary, the function of policy activation is shown in Figure 5.15a. A light oscillation can be found in its behaviour, this oscillation is less damped than the damped oscillation illustrated in the verification, but has the same nature.

A third delay is involved this structure, due to the *Policy activation*. Again, this short term behaviour does not influence the long term behaviour. When possible, the strategy of (unmanned) pick-up points is compared with the base case in the same figure. This strategy leads to less emissions in total. The *Total daily kilometers and the Distance per package* show clearly the start of the policy implementation around 1750 days. The course of the *Total daily kilometers* is oscillating in the short term and the *Distance per package* shows a light angle at that time. The *Policy activation* has a light oscillation in its behaviour, which is reflected in the *Total daily kilometers*. More tours can be made due to the decrease in both delivery as driving time, which leads to a decrease of fleet (Figure 5.10a). Less *Total shipping capacity* is needed, since less packages are in the system due to the lower first time failed delivery rate. All by all, less kilometers are driven, less vans are needed and less capacity is needed. This is a favourable outcome for the government, since this could mean that there will be less negative impacts on the environment and mobility. The logistic efficiency is even more increased when more consumers can be served by pick-up points. An area with a low drop factor, thus less packages per stop and less packages in the same area, is more profitable for this strategy. Since van delivery is already quite optimized in dense areas, and not in sparsely populated areas (ACM, 2020).

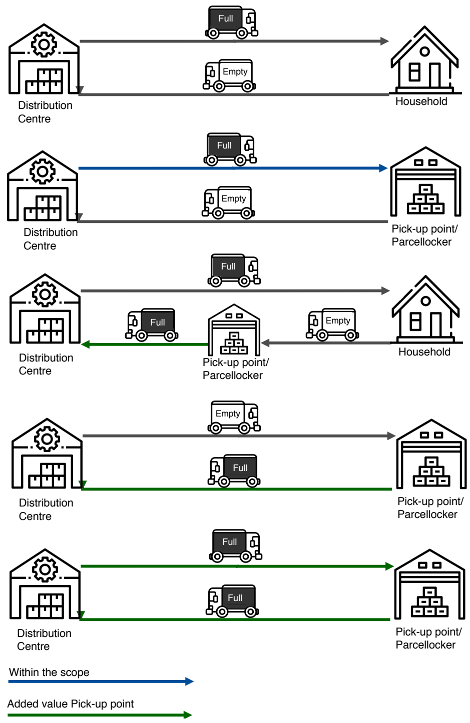
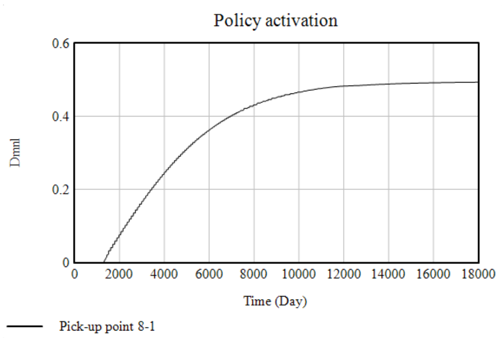
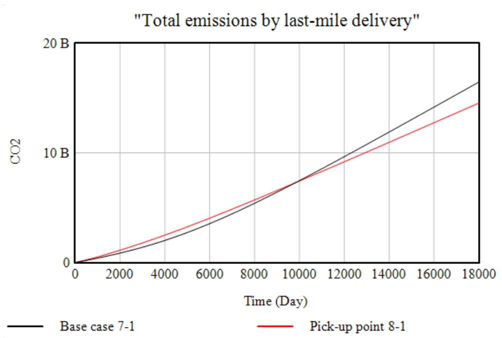


Figure 5.7: Overview of possibilities for full and empty trips

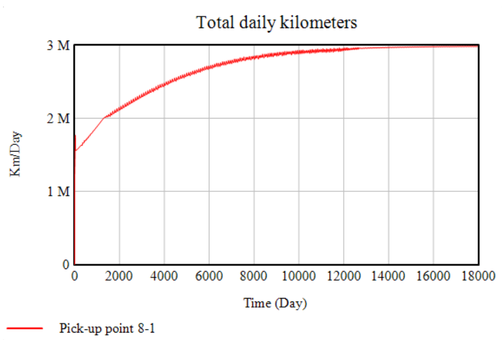


(a) Course of policy activation for (unmanned) Pick-up points

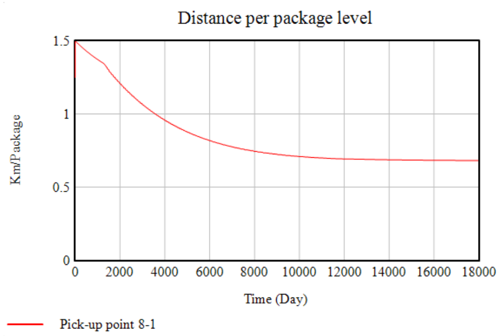


(b) Pick-up point effect on *Total emissions by last-mile delivery*

Figure 5.8: Illustration of *Policy activation* over time & Pick-up point effect on *Total emissions*

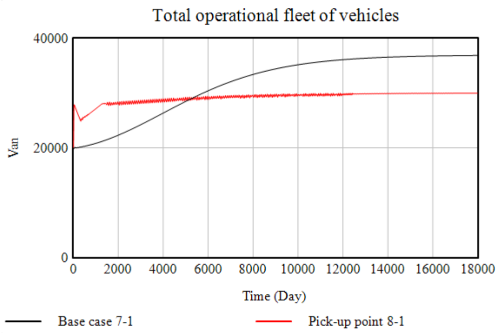


(a) Pick-up point effect on *Daily distance driven for last-mile delivery*

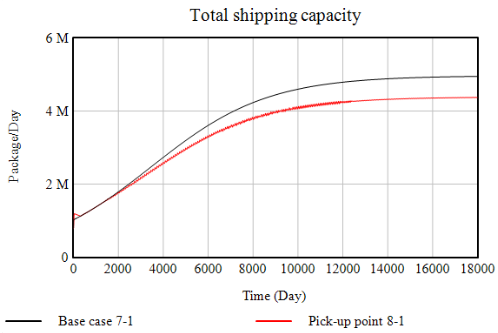


(b) Pick-up point effect on *Distance per package*

Figure 5.9: Pick-up point effect on *Total daily kilometers* & *Distance per package*



(a) Pick-up point effect on *Total operational fleet of vehicles*



(b) Pick-up point effect on *Total shipping capacity*

Figure 5.10: Pick-up point effect on *Total operational fleet of vehicles* & *Total shipping capacity*

5.2.2. Light Electric Freight Vehicles

The second strategy, the use of light electric freight vehicles (LEFV), will have effect on different parameters. LEFV's are electrical driven bikes, mopeds or distribution vehicles, Figure 5.11, and are used next to the use conventional vans. Sometimes they can replace conventional vans, but since the capacity in packages is often lower for LEFV, they are used under more specific circumstances. LEFV's can drive on normal roads and bicycle lanes, but not on highways. The road speed of a LEFV is higher than the road speed of a regular bike, but not as high as the road speed of a van. However in urban areas, the average road speed is set at 25 km/h and a LEFV can also go up to 25 km/h. The difference in speed between a van and a LEFV is thus not that relevant in urban areas. Finally LEFV's pollute nothing. The implementation of LEFV in the model, will affect the load capacity and the amount of CO2 per kilometer, as can be seen in Table 5.4, HvA (2018).

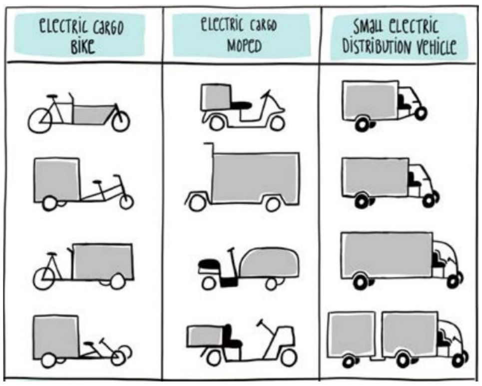


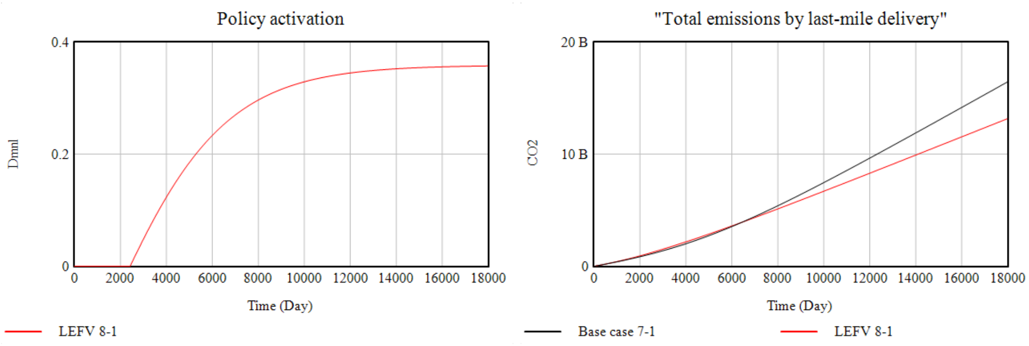
Figure 5.11: Example light electric freight vehicle (HvA, 2018)

The amount of kilometers driven per day, the rate of conventional vans and LEFV's and thus the emissions for last-mile delivery will all be influenced by the increasing use of light electric freight vehicles. Again, this strategy is implemented as a closed-loop policy using the *Policy activation*, which is equal to the ratio of current and accepted daily emissions of CO2. For this strategy both conventional vans and LEFV's are simulated using a distribution key for the ratio of conventional vans and electrical mopeds, based on the *Policy activation*. At the start of the simulation, no LEFV's are operational, the use of LEFV's depends on the Policy activation function. Figure 5.12a and Figure 5.13a, illustrate this around 2200 days. If possible, both the base case as the LEFV strategy are combined in one figure.

Table 5.4: Light electric freight vehicle strategy

Variable	Value base case (delivery van)	Value cargo bike
Base distance from DC to neighbourhood	2x15 km	2x10 km
Packages delivered per tour	40 packages	10 packages
CO2 per driven km per vehicle	0,3 gram/ km	0 gram/ km
Average package delivery time	4 min	3 min

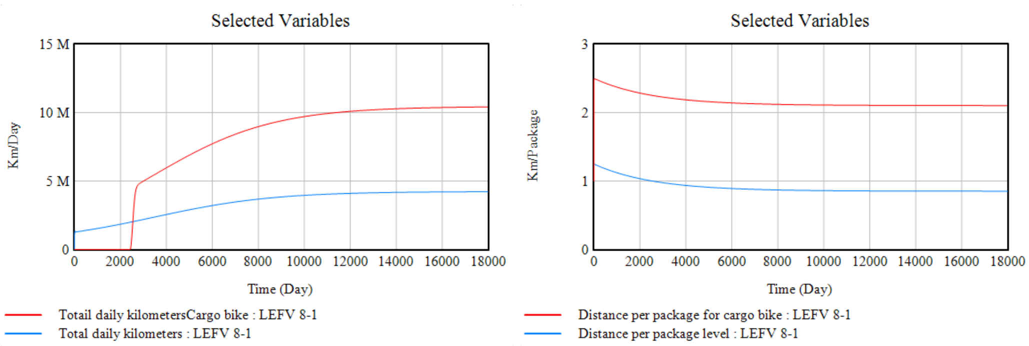
The *Total emissions by last-mile delivery* are lower, as expected, and has a less curvy function, which means that the difference between the two will larger over time. The *Daily distance driven* is more difficult to compare since two types of vehicles with two corresponding logistic characteristics are used. But it is clear that LEFV's drive more kilometers due to their lower load capacity. Based on the different logistic characteristics and vehicle characteristics (Table 5.4), one can estimate that around two LEFV's are needed to replace a conventional van. This explains the big difference in amount of kilometers driven between the two types of vehicles. The *Distance per package* is also higher, again due to the lower capacity. Furthermore, LEFV's can not drive on highways, the vehicles are loaded closer to the delivery area instead of at the DC, which leads to a decrease of base distance (see Table 5.4). This distance is however driven by another vehicle but it is not incorporated in the model. The *Total shipping capacity* in figure 5.14b is equal and the amount of conventional vans (figure 5.14a first increases, but once the policy is activated, the amount decreases a little. A high drop factor is favourable for this strategy (HvA, 2018), due to the lower capacity and the inability to drive on high ways. This strategy results in lower emissions, more traffic movements in total, but less traffic on the main road.



(a) Course of policy activation for LEFV's

(b) LEFV effect on *Total emissions by last-mile delivery*

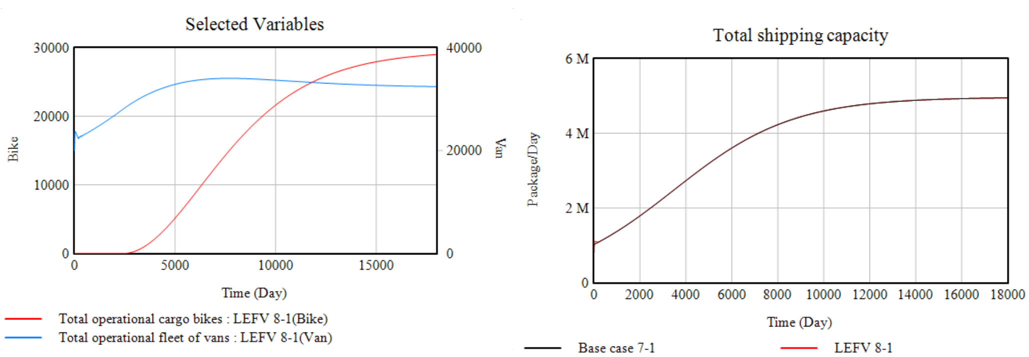
Figure 5.12: LEFV effect on *Policy activation* & *Total emissions*



(a) LEFV effect on *Daily distance driven for last-mile delivery* for LEFV's (in red) and conventional vans (in blue)

(b) LEFV effect on *Distance per package* for LEFV's (in red) and conventional vans (in blue)

Figure 5.13: LEFV effect on *Fleet of vans & LEFV's* & *Total shipping capacity*



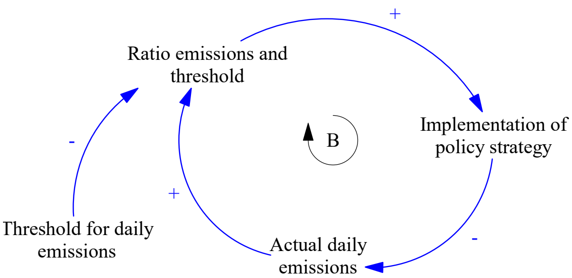
(a) LEFV effect on *Total operational fleet of vehicles* for LEFV's (in red) and for conventional vans (in blue)

(b) LEFV effect on *Total shipping capacity*

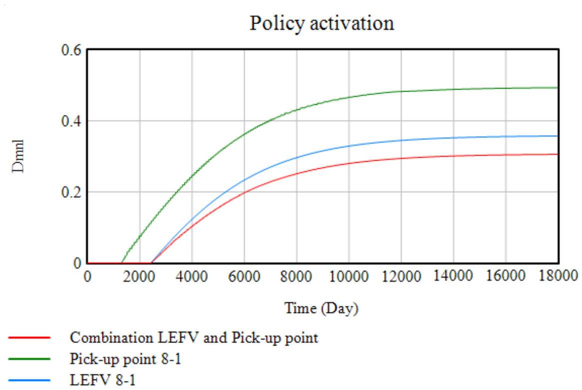
Figure 5.14: LEFV effect on *Fleet of vans & LEFV's* & *Total shipping capacity*

5.2.3. Combination of policy strategies

Both strategies reduce the amount of emissions on their own way. Pick-up points reduce the need of shipping capacity which leads to less emissions and LEFV's are cleaner which also leads to less emissions. The combination of the two strategies is also shortly evaluated by discussing the *Total emissions* and the *Total shipping capacity*, see Figure 5.16. The amount of emissions are the lowest when the two strategies are combined, which means that they complement each other on the effect on this indicator. The *Total shipping capacity* is in between the base case or LEFV strategy and the pick-up point strategy. Which means that implementing only the pick-up point strategy leads to less shipping capacity needed and thus less transportation. The reason for this difference lies in the simulation of the closed-loop policy. The *Policy activation* is based on the ratio of current daily emissions and the set boundary, in the combination the current daily amount of emissions stays continuously a little lower as the two strategies are already activated, see figure 5.15b. The combination is shown in red and is lower than the two others. The need for more policy, is therefore also limited and thus also the effect on the needed *Total shipping capacity*. The use of the pick-up points starts earlier because a higher base distance from DC to neighborhood is set, which results in more daily driven kilometers at the beginning and thus more daily emissions.

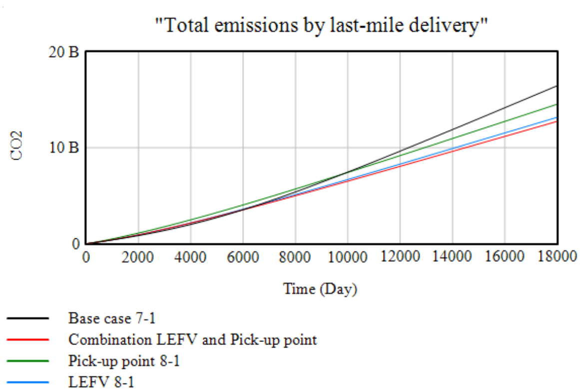


(a) Implementation of policy strategies

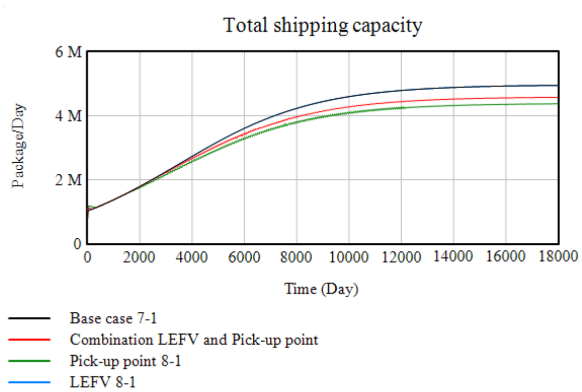


(b) Overview *Policy activation* for all strategies

Figure 5.15: Effect of simulation of closed-loop policy



(a) Combination of Pick-up points and LEFV's on the *Total amount of emissions*



(b) Combination of Pick-up points and LEFV's on the *Total shipping capacity*

Figure 5.16: Combination strategies on *Total emissions* and *Total shipping capacity*

Table 5.5: Changes of KPI's per strategy

Indicator	Start value	Base case	Pick-up point	Light electric freight vehicle	Combination of both strategies
B2C demand [package/day]	*770000*	*381%*	*381%*	*381%*	*381%*
Daily distance by vans [km/day]	1200000	271%	150%	233%	217 %
Total emissions [CO_2]	0	16 B	14 B	13 B	12,5 B
Total fleet of vans [van]	20000	84%	50%	62%	44%
Distance per package [km /package]	1.25	-38%	-46%	-31%	-34%
Total shipping capacity [package /day]	800000	385%	331%	385%	348%

5.3. Scenario's

The strategies are evaluated within the closed system and for specific defined circumstances and showed to be effective within these system boundaries. The values of the exogenous variables are uncertain, as mentioned in the 4.5, therefore the strategies should also be evaluated under different circumstances to eliminate some of these uncertainties and to increase the robustness of the strategies. This is important when recommendations are made about strategies. In this section, four scenario's are formed, based on the exogenous variables and current trends and used to evaluate the strategies.

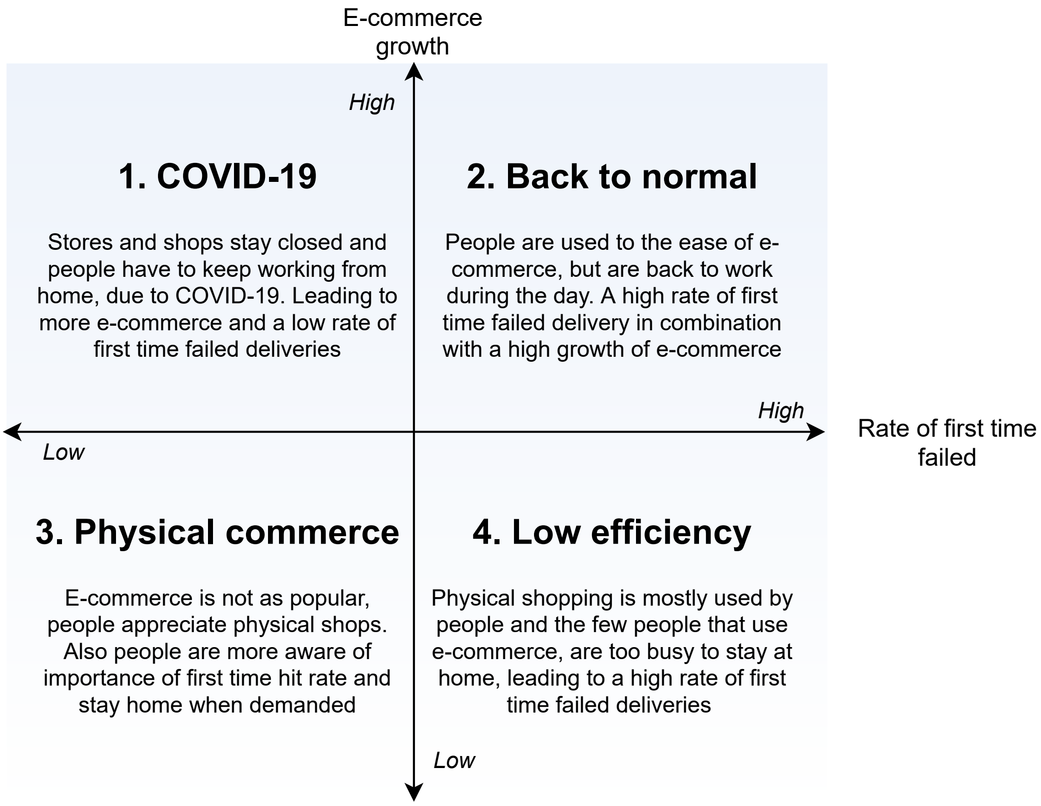
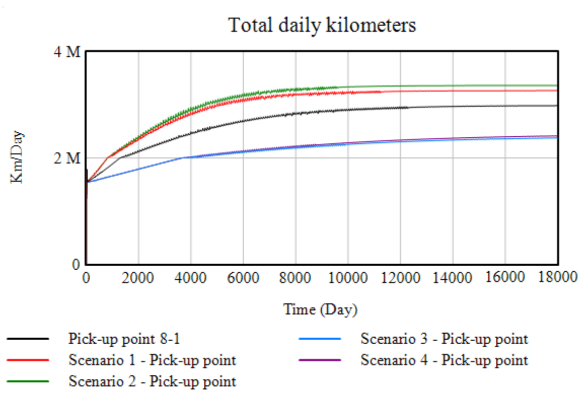


Figure 5.17: Four scenario's with *E-commerce growth* and *Rate of first time failed delivery* as exogenous variables

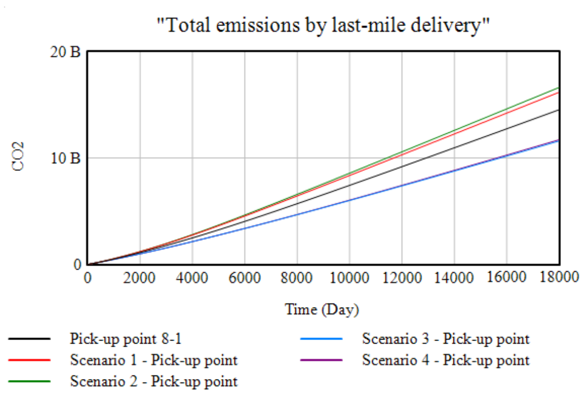
Two exogenous variables are chosen, *E-commerce growth* and *Rate of first time failed deliveries*, both variables are currently extra uncertain due to the COVID-19 pandemic. People use more e-commerce, increase of needed shipping capacity, but are also more at home, which decreases the need of shipping capacity as proved earlier. A high and low value is determined for both variables, and displayed in a grid (Figure 5.17). In the base case, the *E-commerce growth* is 15% per year, the low value is set on 7,5% per year and the high value on 22,5% per year. The *Rate of first time failed delivery* is 25% in the base case, the low value is set on 10% and the high value 30%, as this is already quite high.

Only the effect on the *Total daily distance* and on the *Total emissions* are discussed in this section. Scenario 1, high e-commerce growth and low rate of first time delivery, is for both strategies not favourable. The amount of kilometers driven and the amount of emissions are higher than in the base case of the respective strategies. People are home and not much extra shipping capacity is needed for the failed deliveries. The growth of e-commerce is however significant higher and leads to more kilometers driven for last-mile deliveries and thus more emissions. However, it is not the worst scenario, that is scenario 2. People are used to e-commerce, but can go back to work. This leads to extra capacity needed for the growth of demand and extra capacity due to first time failed deliveries. The combination forces a high amount of kilometers driven and thus a high amount of emissions. Scenario 3 describes a very favourable scenario in this scoped system, since the demand is low and the rate of failed deliveries is low. However the total demand for goods will not decrease, and people will thus go to physical shops. As this transportation is not included in the SD model, the amount of emissions is not well represented in the overall analysis, but especially not in this specific scenario. Lastly, scenario 4, which also seems to be an unfavourable scenario based on the description. However the low e-commerce demand leads again to low kilometers driven for last-mile deliveries and thus to low emissions. Again, the effect of passenger transportation is not included in the SD model.

The behaviour of the KPI's in both strategies and in the different scenarios is in line with its expectations. Scenario 1 and 2 should have the most kilometers driven for last-mile delivery and thus the most impact on the total emissions for both strategies. This is also illustrated in Figure 5.18 & in figures 5.19 and 5.19a. Scenario 3 and 4 should thus logically have less kilometers driven for last-mile delivery since physical shopping is mainly used, which is also the case. The effect of the rate of first time delivery is proportional to the growth of e-commerce for both strategies, since it is defined as a rate of the total amount of shipped packages. Scenario 2 has therefore the most driven kilometers and scenario 3 the least. Also the difference between scenario 1 and 2 is bigger than the difference between scenario 3 and 4, which is again as expected. The strategy pick-up points reduces the rate of first time delivery, but since this is also part of the scenario, the effect of this strategy on the amount of emissions is limited. The use of LEFV's is, based on these scenario's and within the model boundaries, thus more robust against uncertainties. All by all, both strategies show the expected behaviour in all scenario's and are thus robust.

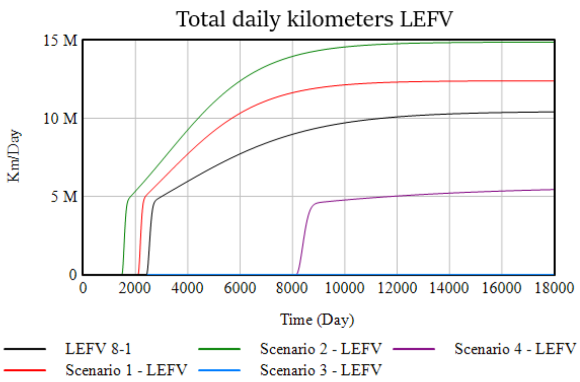


(a) Scenario analysis on *Total daily distance* for Pick-up point strategy

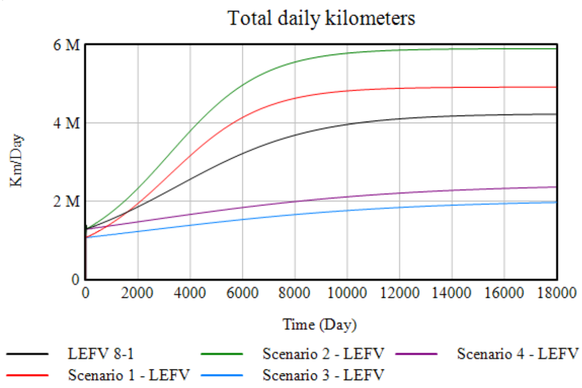


(b) Scenario analysis on *Total emissions* for Pick-up point strategy

Figure 5.18: Scenario analysis for Pick-up point strategy



(a) Scenario analysis on *Total daily distance* of LEFV's for LEFV strategy



(b) Scenario analysis on *Total daily distance* of conventional vans for LEFV strategy

Figure 5.19: Scenario analysis for LEFV strategy

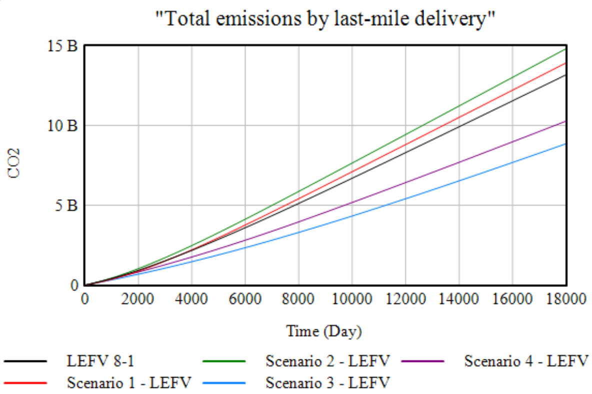


Figure 5.20: Scenario analysis on *Total emissions* for LEFV strategy

5.4. Conclusion Model Application

Five KPI's are evaluated by changing individually six parameters, connected to policy levers. The *Van capacity in packages* and the *Rate of first time failed delivery* are the most influential on the total operational fleet of vehicles, the total amount of kilometers driven for e-commerce and the total emissions for last-mile delivery. This means that changing these parameters with government instruments will have the most impact on the environment and mobility. Changes in the road speed or package delivery time will affect some KPI's, but do not influence the *Distance driven for last-mile delivery*.

Implementing (unmanned) Pick-up points has a lot of benefits, it increases the logistic efficiency of deliveries and leads to less driven kilometers for last-mile deliveries by conventional delivery vans. More packages are successfully delivered the first time, which leads to less capacity needed. The return shipments can also be added to this strategy, and will optimize the delivery even more. Light electric freight vehicles do not optimize the delivery system, but using these vehicles can lead to less road traffic and less emissions as fuel free vehicles are used. Both strategies have more value when a differentiation is made of areas by their drop factor. This is also important for the efficiency of the strategies, regarding the distance driven per package. The use of pick-up points lead to the lowest distance driven per package. In the strategy of LEFV's, the distance per package driven by conventional delivery vans is slightly higher than the base case, and the distance driven per package driven by LEFV's is much higher due to its smaller capacity in packages.

6 Conclusion

This chapter will provide a conclusion on the research. The main objective of the research was to clarify the relations between B2C e-commerce of goods and the amount of kilometers driven for last-mile delivery, and eventually to estimate the impact on the environment and mobility in the Netherlands. The research questions supporting the objectives are discussed first, followed by a concise answer to the main research question.

6.1. Research Conclusions

In this study, a conceptual model and a system dynamics model are developed. These are used to clarify and to assess the effects of e-commerce growth on the amount of kilometers driven for last-mile delivery. A literature review and a problem analysis are used to create the conceptual model and describe the qualitative relations between the e-commerce market and the logistic sector. Available government instruments and the corresponding policy levers to reduce the negative impacts, are also identified in the problem analysis. The relations within the logistic sector and e-commerce effects on the logistic sector are quantified in a simulation model using System Dynamics. Next, the effect of the individual policy levers on the key indicators of the system dynamics model were analysed. Different scenarios were built to test robustness of the strategies for uncertainties. The results and insights are discussed per research question, and answer together the following main research question.

How will the growth of the B2C e-commerce demand and supply, influence the amount of kilometers driven for last-mile deliveries by conventional delivery vans in the medium to long term?

RQ1: How can the relationship between e-commerce demand and the corresponding logistic sector be described qualitatively?

The conceptual model is formed using literature and a problem analysis is used to describe the relations. Mainly two theories are used to describe the link between e-commerce and the amount of kilometers driven for last-mile delivery by the logistic sector. Firstly the Supply and Demand theory, this theory explains why and how transactions are made between suppliers and consumers. The second theory, the Transport Layer Model, explains the structure between different transport services of the logistic sector and their link with one another. The transportation of the online bought purchases to the consumer, often via a logistic service provider, links the two theories. The e-commerce supplier is responsible for the delivery and the consumer can choose, between the available delivery options, their desired delivery type. The consumer and the e-commerce supplier are thus linked via the supply and demand theory. The logistic service provider is linked to the e-commerce supplier via a contract, but has no formal link with the consumer. The blue boxes in figure 6.1 illustrate the above stated relations.

RQ2: How can the relationship between macro-effects and micro-behaviour be described qualitatively?

As mentioned in the answer of the first research question, two theories explain the main relationships between the e-commerce market and the logistic sector. A more detailed explanation of these theories together with a description of the macro-effects answers this research question.

Scarcity, a concept within the supply and demand theory, determines the value of the product and thus the price. This works also the other way around, and this creates competition. Online shopping

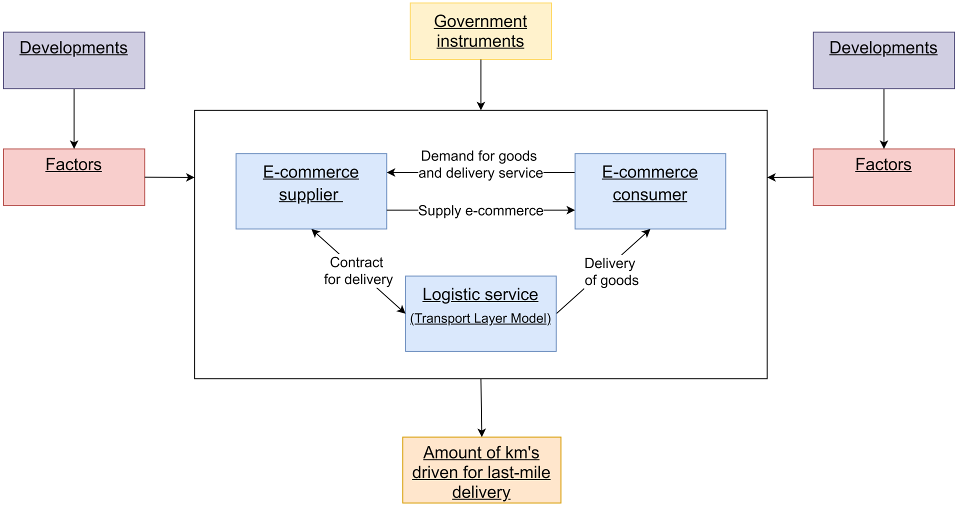


Figure 6.1: Simplification of relationship between macro-effects and micro-behaviour

works with the same principle, except the logistic sector is in this case also involved. The competition is not only based on prices but also on service of the last-mile delivery. Concepts promoted on platforms of e-commerce suppliers, like next-day delivery or free return shipments for the consumer, are part of the competition and belong within the logistic sector. The different transport services in the Transport Layer Model are all touched by the e-commerce sector. The first transport service, is the used infrastructure (the Traffic market) and this service defines, the second service (Transport market): the type of vehicles that can be used on that infrastructure. The type of vehicle defines the type of goods (the Freight market) that can be transported with that vehicle. This series of links is simultaneously also followed backwards, the Freight market defines the Transport market which defines the Traffic market. A service offered on a platform of an e-commerce supplier, for instance next-day delivery, requires a robust logistic infrastructure, with a responsive fleet of vehicles that arrives within the right time slot at the delivery location. Consumers value this service highly, which can be linked back to the e-commerce supplier. The delivery of packages is mainly active on the Transport and Freight market.

All transportation for e-commerce by conventional vans result in negative impacts, like pollution and congestion. The government, another key actor group, wants to reduce these negative impacts using government instruments on policy levers. Furthermore, external factors, like the familiarity with internet and electrification, influence the supply and demand of e-commerce and the logistic sector. Next, developments like COVID-19, influences these factors. Eventually, every aspect also influences the negative impacts via the e-commerce market and the logistic sector, shown in Figure 6.1. All these above mentioned links, make the relation between e-commerce demand and the logistic sector, and thus the amount of kilometers driven for last-mile deliveries by conventional vans, complex, as dynamic links and feedback links are part of the system.

RQ3: What are the likely quantified impacts of e-commerce demand on the amount of kilometers driven for last-mile delivery by conventional delivery vans?

A simulation model is built to quantify the impacts using System Dynamics (SD). Based on the conceptual model, system boundaries are set for the simulation model. The most relevant components within the system boundaries are illustrated in a Bull's eye Diagram. Then, the relations within the system boundaries are illustrated in a Causal Loop Diagram (CLD). This diagram forms the basis of the system dynamics model. The dynamics illustrated in the conceptual model and in the CLD suggest that System Dynamics is an appropriate method to simulate the system, as several feedback loops are involved. Besides, System Dynamics is strong in the visualization of complex systems, it permits to simulate accumulation, delays and it can also be used with only little data.

The sub models in the simulation model are simplified displayed in the CLD (Figure 6.2). The blue arrows illustrated the package flow, this flow is built to simulate the supply chain of package deliveries, including the *Negative feedback loop packages* that represents the outflow of packages of a distribution centre. The *B2B delivered packages* in the CLD represents the growth of e-commerce.

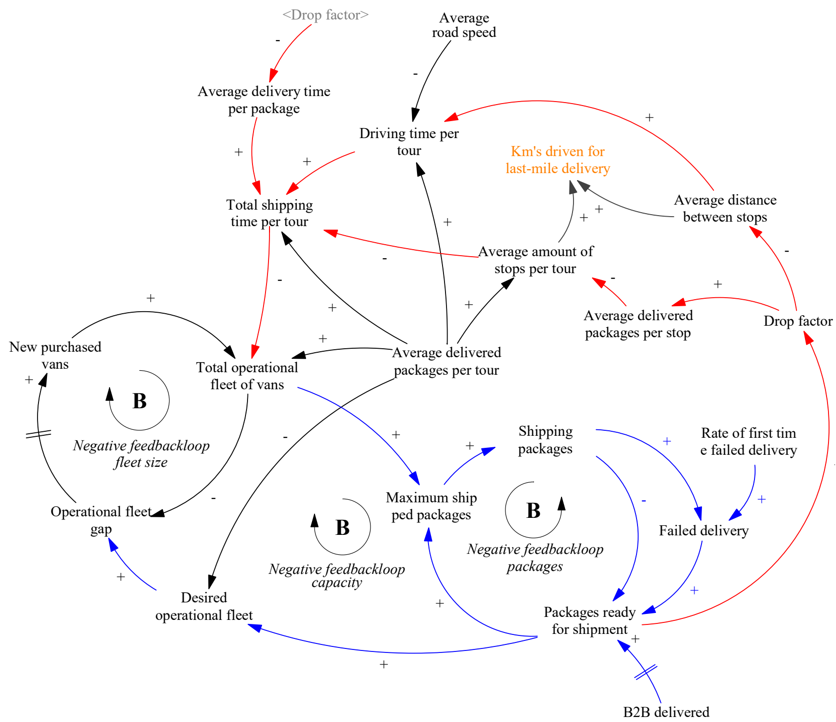


Figure 6.2: Causal loop diagram showing the relation of e-commerce demand and the amount of kilometers driven for last-mile delivery

Its equivalent in the package flow sub model is the main exogenous variable of the system dynamics model and is set on a 15% growth per year at the beginning, this grow will eventually slow down, which creates a s-curve growth. The logistic characteristics from the Freight and Transport Markets of the Transport Layer Model are simulated in the sub model for logistic capacity. The red arrows in the CLD represents this sub-model. Finally, a fleet sub model is created to simulate the balancing feedback loop *Negative feedback loop fleet size* from the CLD. The links between the fleet size and the package supply chain is also a feedback loop, *Negative feedback loop capacity*. Based on the CLD, it can be concluded that even though there is an increase of e-commerce, this does not lead to an equal increase of transportation. The simulation model quantifies and evaluates this effect of e-commerce on the amount of kilometers driven for last-mile delivery and for four other Key Performance Indicators (KPI). These indicators are chosen based on the different negative impacts and available parameters in the SD model. Different verification tests and validation tests are conducted and established that the model results can be used for the purpose of the model and within its system boundaries.

The negative impacts on the environment and mobility are linked in this research to the total amount of kilometers driven for last-mile deliveries. The more daily kilometers are driven by conventional vans, the more emissions and the more traffic. Next to the daily amount of kilometers, the distance per package and the total shipping capacity is evaluated to have a more detailed perspective of the total effect. The distance per package can indicated the logistic efficiency of the deliveries and the total shipping capacity illustrates the total need for transport capacity to deliver all the packages. It can be concluded that the growth of e-commerce does not lead to an equal growth of the amount of kilometers driven for e-commerce. The main reason is that the growth leads to logistic efficiency, like shorter distances between the delivery stops and more packages delivered per stop. The distance per package is decreasing, however only asymptotic as there will always be a minimum amount of kilometers to drive. The increase of total kilometers, the decrease of distance per package and the increase of total shipping capacity, indicate that there is more transport in total. This leads to negative impacts on the environment and mobility, less traffic safety and more congestion. The negative impacts will grow, only not with the same magnitude as the growth of e-commerce.

RQ4: How can policy anticipate on the e-commerce growth to minimize the impacts on the environment and mobility?

Two strategies are implemented in the simulation and again evaluated by the KPI's to determine its effect on the total kilometers driven and thus the impact on the environment and mobility. The first scenario describes the use of (unmanned) pick-up points instead of home deliveries. The use of (unmanned) pick-up points is a known solution and the government has indicated that municipalities could ease the implementation of these points by a standardization of licensing for these points. This could be in combination with granting subsidies for building an unmanned pick-up point. Lastly, a national campaign, to promote the use of pick-up points, could be started. This also creates awareness about this delivery option among citizens. The passenger transport needed to pick-up the packages is not incorporated in the system boundaries. The main differences with the base case set up lies in the rate of first time failed delivery, the distance between the delivery stops and the amount of packages delivered per stop. The stops are in this scenario the pick-up points and they lie further away from each other than in the base case. However more packages are delivered per stop. This increases the logistic efficiency, indicated by the distance per package. Also less transport capacity needed as more packages are successfully delivered the first time around. This scenario can best be used in areas with a low drop factor of packages since this will be more profitable for the logistic service provider. More pick-up points also reduces the distance between households and the pick-up points which leads to less passenger transport and makes it more advantageous for consumers to use this option.

The second strategy simulates the use of light electric freight vehicles (LEFV). Also this strategy is already known, and the government can contribute to the use of these vehicles with an incentive scheme. A more authoritative intervention, related to law and regulation, could be a restriction of entering an area by a conventional delivery van. This would either push logistic service providers to use other types of vehicles, like LEFV's, or lead to more pick-up points at the border of that specific area. LEFV's are simulated with less capacity of packages per vehicle and with a shorter distance between the distribution centre and the area of deliveries. The LEFV's are supplied closer to the urban area since they can not drive on highways. The vehicles can however use bicycle lanes. This results in more vehicles in total, more kilometers and a higher distance per package than in the base case. The transport capacity stays logically equal. This means that more traffic movements are made. However, since LEFV's can drive on bicycle lanes, less traffic movements are made on the road, which is beneficial for the traffic safety and congestion. In dense areas, like city centres, this effect is even more relevant. Also, the total emissions are lower since LEFV's are electric and thus less polluting than conventional delivery vans.

RQ5: Which improvements can be made in the CBS survey for the next years to gain more consistency of data?

Data of the CBS about delivery vans in the post sector was used for several parameters in the SD model. Numbers related to the freight and transport market were mainly provided, such as the van capacity in packages, the amount of kilometers driven per conventional van per year and the amount of stops made by the vehicles. The type of vehicle was known and the sector in general (the post sector). However, literature showed that there are different e-commerce segments with each their own set of logistic characteristic. The delivery of white goods has, for example, less stops per day than a small parcel service. Also, the difference between business to business deliveries or business to consumer deliveries can lead to differences of data sets. Adding a question regarding the different sectors and segments within the post sector could lead to much more specialisation of the data. And will help to compare different data sets. This could also be done by asking about specific characteristics, like the inclusion of special services during the delivery, such as the installation of white goods.

Main research question

The growth of B2C e-commerce will, no matter the type of growth, increase the amount of kilometers driven for last-mile deliveries by conventional delivery in the medium to long term. Via the need for more transport capacity, more conventional delivery vans are used and more kilometers are driven per vehicle. More people use e-commerce and the demand per consumer grows, which results to more packages delivered per stop and more stops per area. This leads to logistic efficiency of the delivery system. The growth of B2C e-commerce will therefore not impact the amount of kilometers driven for last-mile deliveries with the same magnitude.

7 Discussion & Recommendations

In the previous chapter, the results were summarised which leads to the next step, the discussion of those results and the corresponding recommendations for further research.

Firstly the limitations concerning the model scope, assumptions and results are discussed. Followed by a discussion about the use of methods, especially the use of System Dynamics in the freight transport field.

7.1. Contributions

First the scientific contributions are discussed, followed by the societal contributions.

A conceptual model is made to create an overview of relevant components between the e-commerce market and the logistic sector. The simulation model only quantifies a part of this conceptual model, further research can use the conceptual model for further research. Next, literature mentions that the growth of e-commerce effects the logistic sector and states that this growth will not lead to the same growth of amount of vehicles or amount of driven kilometers. This research has shown which relations lead to this fact and how the growth does influence the amount of kilometers driven for last-mile delivery. Finally, within the transportation field, and especially the freight transportation field, only little models are available using System Dynamics (SD). Higher aggregation levels are mostly used for transport SD models. Transportation also includes micro behaviour and discrete elements. The combination of lower aggregation levels, like the package flow, and higher levels are combined in the SD model of this research. The insights concerning logistic efficiency, where found due to this combination. Further research could continue with the quantification of the conceptual model, using SD, on different aggregation levels.

The options for government intervention are discussed, by analysing different policy levers and policy strategies. Both the use of pick-up points as the use of light electric freight vehicles are found to reduce the impact on the environment on their on way. The so-called *first time hit* rate is an important parameter for reducing the amount of emissions, as it reduces the amount of transport capacity needed. The government and logistic service providers could focus more on this aspect, also in combination with the use of electric vehicles, which is more common.

7.2. Results

The research question aims to clarify the relation between e-commerce growth and the amount of kilometers driven for these last-mile kilometers, to know more about the effect on the environment and mobility in the Netherlands. A conceptual model is made to create a framework of the relevant theories and relations between the different elements, and a system dynamic model is build to quantify the relevant relations within the conceptual model. The growth of e-commerce leads to efficiency of the logistic capacity via three variables, the amount of packages delivered per stop, the amount of stops made per kilometer and the delivery time needed per package. This quantitative model illustrates that this influence of e-commerce growth leads to a disproportional growth of the amount of kilometers driven for last-mile deliveries, due to the logistic efficiency gained. This link also leads to a disproportional growth of the amount of vehicles needed for last-mile deliveries, which explains the small growth of the fleet.

Urban characteristics

In the first stage of the research, in the problem analysis, many aspects were mentioned and relations were discussed. Further on in the research, this complexity leaded to a very scoped simulation model in order to handle this complexity. The assumptions made, lead to a working but general system. The results are valid for the purpose of the model, however when translating these results on the effect on the environment and mobility, the model boundaries should be kept in mind. First, only urban freight transport is included and not passenger transport. The possible gains or losses of home delivery instead of individual passenger transport are therefore excluded. Further research could combine the dynamics between the decrease of passenger transport and the increase of freight transport. Next, the same type of region, urban areas, was considered for all deliveries in the model, which can again lead to excluded gains and losses of the efficiency of last-mile deliveries. This statement is linked to the so-called *Drop-factor*, the amount of packages delivered per km. A dense urban area, will have a higher drop-factor than a more sparsely populated urban area, and will thus have less benefits of the logistic efficiency via the three variables. The model simulates only one type of urban area, an average urban area, and thus an average amount of logistic efficiency probably. A follow-up research could investigate the bandwidth of the logistic efficiency gained for different urban areas, but also for rural areas.

Freight market characteristics

Furthermore, for every vehicle the same amount of packages in the vehicle is assumed. The amount of packages loaded in the van can vary for several reasons, like size of package, loading tactics or simply the demand on that day. Setting the vehicle capacity as exogenous variable, made it possible to model the potential logistic efficiency, without taking business tactics or daily changes into account. The model is however quite sensitive to this variable, further research could evaluate this variable and the different business tactics more extensive in cooperation with a logistic company. Additionally, the efficiency of the delivery system is influenced by the distance between the delivery locations, the stops. The density of the urban area is a factor that influences this variable, but also the demand of the e-commerce segment. The conceptual model shows that the e-commerce segments have different freight market characteristics, including the freight volumes and region of operations. The system dynamic model simulates the effect of e-commerce growth for the average segment, this shows the general effect of e-commerce growth on the amount of kilometers driven for last-mile delivery. Business strategies can not influence the behaviour of this relation in the model. However, business strategies can influence this relation and further research could look into the different e-commerce segments and the strategies within every segment to get a better understanding of the behaviour per segment.

Effect on environment & mobility

Finally, the amount of kilometers driven for last-mile delivery is used as main indicator for the effect on the environment an mobility in the Netherlands. By translating the amount of kilometers directly to the impact on the environment, a very linear relation is used which does not reflect the whole relation. The impact of the environment is also influenced by the amount of stops made for example, as acceleration is more polluting that driving at a constant speed (Shridhar Bokare and Kumar Maurya, 2013). This makes is also difficult to draw conclusions about the feasibility of as much as possible emission free city logistics by 2025, as part of the Green Deal. The same can be said for the translation of the indicators to mobility impacts. Mobility can be described as the amount of traffic, but also the efficiency of the transportation's, the freight transported, the modal split and traffic safety. The impact on mobility is in this research quantified by analyzing the amount of kilometers driven, the amount of shipping capacity and the fleet. An increase of all parameters leads to more mobility and less traffic safety. Based on the model, the impact on mobility will increase due to the growth of e-commerce. But, the distribution of all transportation over the day is also needed to know the impact on the mobility. If all transportation takes place at the same time in the same area, then the impact is much higher in comparison with a distribution of the transportation's over the day and the country. Further research could add spatial and/or time of day distribution of the transportation's to the research scope and give more insights in the specific impacts on the environment and mobility over time and place.

7.3. System Dynamics

The problem analysis showed that the relation between the growth of e-commerce and the amount of kilometers driven for last-mile delivery is very complex with many different dynamic relations between the elements. Feedback loops and delays were established, which lead System Dynamics to be one of the research methods.

System Dynamics & Transport Systems

Literature indicated that transportation issues are not the most common field of research for system dynamics, however the reason for this is less indicated. Further research could investigate possible reasons and summarize causes for this event in a paper. In this research, a combination of different aggregation levels was used to simulate the system correctly. On a low aggregation level, transportation has often discrete characteristics which can influence the high aggregation level. This combination can be challenging when setting the model boundaries and can be a reason for the scarcity of transport related SD research. Every day decisions are the main drive of the system behaviour in this system dynamic model. The medium term influence of e-commerce growth on the amount of kilometers is therefore illustrated. However macro effects and macro behaviour are less represented in the model, like the behaviour of the fleet when new policy is implemented. Further research could focus on macro behaviour and build a model that simulates the dynamics between e-commerce and the logistic sector on a more aggregated level.

Related to this discussion, is the next point of discussion. The system dynamic model does incorporate different vehicles at the same time, and does incorporate different delivery options, at home or at pick-up point, at the same time. However only superficially, the policy implementation is based on a simple environmental threshold. The use of electric vehicles might be more sustainable, but they are less familiar currently than conventional vans and require a higher investment. They are also bounded to a range, which should be kept in mind when planning the delivery round. The choice behaviour of the logistic service supplier is therefore also relevant. Subsidies can help, but the model does not show the dynamics related to this instrument. Using pick-up points might also be better, but if consumers are not willing to adapt, this strategy will not be as effective as concluded. All by all, it is necessary to research other aspects of the strategies before implementing these.

Other methods

Altogether, the generality of the model, created by the above mentioned, makes it more important to translate the model results to overall conclusions without the system boundaries. One could also say that System Dynamics was not the right method for this system. Only little feedback loops and delays are incorporated in the system. However more System Dynamics is also very useful for visualizing system, which can be used as communication tool in discussions. Also its power to conceptualize accumulations and delays was used in the simulation model. Furthermore, the conceptual model used qualitative system dynamics as method to clarify the relations. In the Literature review the strengths and weaknesses were displayed, one of the weaknesses was the lack of literature in the freight transportation field. The use of this method on this type of system can therefore be seen as a contribution on itself. The tool, Vensim, is used to build the SD model in this research. A more simple tool, like Excel, could also be used as this research has limited amount of feedback loops and delays compared to other SD models. The strength of spreadsheet tools is modelling linear relations and calculating statistics about an issue. A complicated spreadsheet would be necessary to simulate the dynamics. Next, the visual representation of spreadsheets is not favourable for dynamic systems. The relations between the variables is less clear and make it more difficult to understand the dynamic issues over time. Agent Based Modelling (ABM) could also be used to model this system from bottom-up instead of top-down. The emphasis of such a model lies on the interactions between the different actors instead of the overall behaviour of the system. This makes it a appropriate method to simulate the discrete elements of a transport system and of the lower aggregation level of this research system. The two methods are complementary, ABM could be used to simulate lower aggregation level and the results can then be used in the SD model for the higher aggregation levels in further research.

7.4. Data

In the SD model, data was needed to quantify the relations and assumptions were made when data was unclear or unavailable. Data from CBS and Thuiswinkel.org were mostly used, the latter one mainly for e-commerce related data, like the size of the B2C e-commerce sector and CBS for transport related data, like the average amount of packages loaded per vehicle. As the model simulated the average urban city and the average e-commerce segment regarding the freight market, general data was enough. As just mentioned, the model could benefit from more differentiation in the e-commerce segments and urban areas. Currently, CBS administers only several branches in online sales (Retail, multi-channel, mail order companies and web shops), while more segments are identified in literature, such as general cargo or temperature controlled cargo. Also, the type of e-commerce, B2B or B2C, was not always mentioned, which can easily to big differences in data sets. Further research could gather data related to these specific segments, like the average amount of deliveries or stops per day and the size of the region of operation. The research of CE Delft (2017) already provided some data regarding this differentiation, however for more extensive calculations averages were again used.

7.5. Summary of recommendations

In the previous sections of this chapter, several recommendations were made. These will be summarized in this section to give an overview of all recommendations.

Scope

The availability of e-commerce leads not only to more freight transport by conventional vans, but also to less passenger transport to physical shops. The dynamics with passenger transport were excluded in this research, further research could evaluate the dynamics between passenger transport and freight transport. Also, less freight transport to physical shops is probably needed to deliver the inventory. The influence of this freight flow on the amount of kilometers driven for retail purposes, could also be researched. Furthermore, the influence of time and location of the transportation is not included, whilst this can have great influence on daily congestion. Further research could add spatial and/ or time of day distribution to the simulation model and give more insights in the specific impacts on the environment and mobility over time and place. Next, the optimization possibilities of delivery systems in different urban areas can be researched. The density of an urban area, can lead to more logistic efficiency whilst rural areas to less efficiency of transportation. The same type of research can be conducted for the different e-commerce segments and the possible business strategies within every segment, to get a better understanding of the behaviour per segment.

Method

Literature indicates the little amount of system dynamic research in the transport field of research, however reasons for this event are not given. Further research could investigate possible reasons and summarize causes for this in a paper. Next, macro behaviour between e-commerce and the logistic sector is little simulated in this model. Additional research could focus on system boundaries on a more aggregated level. To complement higher aggregated models of SD, Agent Based Modelling could be used to simulate low aggregated systems in further research, to complement SD models.

Data

Finally, further research could gather data related to specific e-commerce segments, like the average amount of deliveries or stops per day and the size of the region of operation. The research of CE Delft (2017) already provided some data regarding this differentiation, however for more extensive calculations averages were again used.

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A

Scientific Paper

The effects of e-commerce growth on the environment and mobility

A.S.M. Heinen, Dr. M. de Bok, Dr. F. d'Hont, Dr. J. Visser, Dr. A. van Binsbergen, Dr. L. Tavasszy

Abstract - **This research clarifies the relations between the growing e-commerce sector and the logistic sector. The last-mile transportation of goods bought via e-commerce is growing, which leads to negative impacts on the environment and mobility. A Causal Loop Diagram (CLD) illustrating the relations is made and a simulation model is build quantifying these relations, for both models System Dynamics (SD) is used. The models are based on literature and data from CBS. Strategies are developed to assess two policy strategies, the use of (unmanned) pick-up points and the use of light electric freight vehicles (LEFV). The growth of e-commerce leads to logistic efficiency at the beginning, but eventually this efficiency growth will stop. Currently their is still logistic efficiency gained, this results in a less steeper growth of the negative impacts. The use of pick-up points is based on the same parameters providing the logistic efficiencies and are a strong long term solution to the growth. Furthermore, using pick-up points increases the rate of successful first time delivery, this results in less needed shipping capacity. Passenger transport is needed to pick-up the package, this effect is not incorporated. The use of LEFV's reduces the amount of emitted pollution and the amount of road traffic movements. However more vehicles are needed and the traffic movements will only be moved to bicycle lanes. Both strategies are realistic and some logistic service providers are already implementing the strategies.**

Keywords - E-commerce growth, Supply-chain operations, Logistic efficiency, System Dynamics, Last-mile delivery

Introduction

Business to consumer (B2C) e-commerce has grown considerately the last decade due to several factors like the increase of familiarity with internet and online shopping. Also more applications are available that facilitate e-commerce (Allen et al., 2018). Developments, like COVID-19, influence on their turn the factors (Taylor and McCombe, 2020). The growth is currently around 15% and it is not expected to decline the coming years (ACM, 2020; Roland Berger, 2017). Part of e-commerce is the delivery of the purchases to the consumers, which is executed by mostly delivery vans owned by logistic service suppliers (CE Delft, 2017). Competition in the e-commerce sector often involves this logistic sector, e-commerce providers offer, in collaboration with logistic service providers, next-day delivery or free return shipments for the consumers (Allen et al., 2018). All these elements influence the logistic sector, and make the delivery system quite complex. The growth of e-commerce impacts, via kilometers driven for the transportation of packages, the environment and mobility in the Netherlands. The government can intervene by using government instruments and policy strategies. Figure A.1 shows an overview of all components.

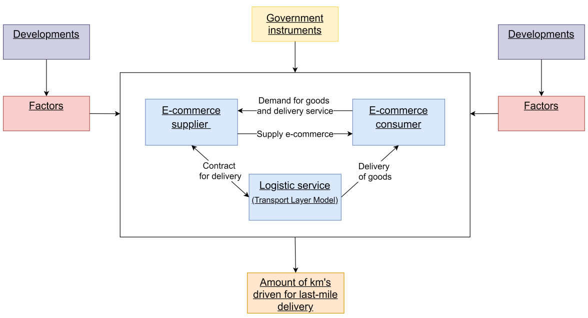


Figure A.1: Simplification of the e-commerce market and logistic sector

The amount kilometers driven by delivery vans is around 50% higher than driven by other vans. Also the amount of delivery vans used for the last-mile deliveries did not increase proportional to the growth of e-commerce, the increase was less (CE Delft, 2017). The impact of transportation for last-mile deliveries can therefore also not be directly linked to the growth of e-commerce. In this research paper the relation between e-commerce growth and the amount of kilometers driven for last-mile delivery will be clarified, to give more insights in the effect of e-commerce on the environment and mobility. The corresponding research question is as followed: *How will the growth of the B2C e-commerce demand and supply influence the amount of kilometres driven for last-mile deliveries by conventional delivery vans in the medium to long term?*

Research Approach

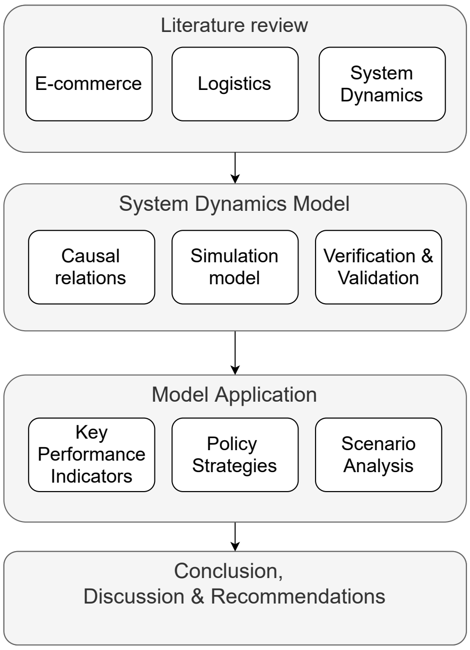


Figure A.2: Research approach

First, a literature review is conducted which is used later for setting the model boundaries. The elements needed for the simulation of the relation between e-commerce and the amount of kilometers, are extracted. Which leads to the set up of the simulation model. Model boundaries are set, followed by a Causal Loop Diagram (CLD) illustrating the most relevant relations. The simulation is a system dynamics model in the software package Vensim. Indicators are determined to analyze the behaviour of the scoped system. Next, policy strategies are established and analyzed to determine the influence of these strategies on the amount of kilometers driven for last-mile delivery and eventually the impact on the environment and mobility. Scenario's, based on e-commerce growth and the first time hit rate, are used to analyze the robustness of policy strategies. In the next figure, Figure A.2, the research approach is illustrated.

Literature review

In this literature review, three topics are discussed. Two topics related to the problem: E-commerce, Logistics. These will mainly be used for model development. The last topic is related to one of the methods: System Dynamics.

E-commerce

E-commerce is the online commercial transaction between parties (Visser et al., 2014), a customer and a retailer, and more generically speaking, a demand and a supply side. Both sides are influenced by each other as described in the conventional economic theory of Marshall (1980), the demand side can only buy what is offered and the supply side reacts on the demand curve to improve its supply. The theory can be applied for e-commerce, with the online interaction as market place. The different types of demand and supply determines the type of e-commerce: Business to Consumer (B2C), Business to Business (B2B) and Consumer to Consumer (C2C). Transactions made by e-commerce can concern goods and services, a service can be the purchase of flight tickets online. This paper focuses on the e-commerce of goods from B2C. Goods need to be delivered to the consumer, the transportation of goods is therefore part of the service offered by the e-commerce supplier. The type of goods are quite influential for the type of transport, a large product can logically not be delivered by cargo bike and a home-delivered meal is not going to be delivered by a truck as can be imaged. The Transport Layer Model (TLM) will elaborate this phenomenon in the next section. A variety of segments can be found within e-commerce for goods, like general cargo, temperature controlled cargo or parcels & express cargo. Every segment has different characteristics as is thus also differently influenced by the growth of e-commerce.

Logistics

The growth of e-commerce leads consequently also leads to a growth of freight transport and changes in the logistic sector (Burt and Sparks, 2003). The most used vehicles for this type of freight transport are delivery vans, the increase in amount of delivery vans is not equal to increase of e-commerce use the amount of vans is slightly increasing. However, the comparison in yearly amount of kilometers driven between vans used for e-commerce and vans used for other activities (private or business), is interesting. The vans used for e-commerce drive in general 50 percent more kilometers per year than the ones used for other activities (CE Delft, 2017). This can be explained by the fact that delivery vans are used continuously during the day, where as a plumber only uses it to go from one address to the other whilst the main activity in inside the house. The large amount of kilometers is still no complete explanation for the small increase of delivery vans. The type of difference between a plumber and last-mile delivery is also present within last-mile delivery sector. The last-mile delivery planning is quite complex, there are a lot of variables that contribute to the outcome of the supply chain characteristics, routing and planning: time frames, types of goods and their services required, types of vehicles, peak pressure, costs, but also the use of parcellockers or pick-up points as specified in the latter paragraph and in the Scope. The difference between the delivery of white goods and mailbox sized parcels can be used to illustrate the variations. White goods, like a washing machine, are often be installed when delivered. This requires more skills of the drivers and is also quite time-consuming. The amount of stops that they can make during a tour or day is consequently quite low. The delivery of mailbox sized parcels is in comparison less complicated for the drivers and also faster, which consequently leads to more stops per tour. In addition, the demand for white goods is in comparison with parcels lower (CE Delft, 2017), logically the distance between the households is larger in this case. To sum up, within last-mile delivery, a lot of variations can be established that all add to the complexity of delivery supply chain.

System Dynamics
In 1961 Forrester developed this method to investigate the economic, business and organisational systems. This methodology is able to explain the effects of decisions made in complex systems, by illustrating the internal relations and structures and external interdependencies (Thaller et al., 2017). Feedback loops and time delays can be used to represent these dynamics. The model can be used both qualitative as quantitative, with each way their advantages and disadvantages. The method was originally developed as quantitative model, but shortly after some argued that the quantitative aspect dominated the method whilst the other aspect of the method, 'system thinking' or 'qualitative system dynamics', was also valuable. Where qualitative models are quite strong in mapping structures and feedback loops, they could also be misleading in their insights, which can intentionally be used by people, or when people are inexperienced with the method. Quantitative models can illustrate behaviour of a system over time by using non-linear and differential equations and data, however validating such models can be quite complicated and sufficient experience is needed to do so (Wolstenholme, 1999). Most of the research that is in this field, aims to understand and assess the impacts of instruments for transport policies, mostly policies concerning passenger transportation and spatial effects/developments are investigated. Models about freight transportation are in the minority and therefore only a few studies can be used for the literature review. Within these studies some have a very broad scope (regional, national, international) whilst some focus on the structures between the freight transport and the logistic choices along the supply chain (Clausen et al., 2016). Several papers discuss the applicability of system dynamics on transportation systems (Abbas and Bell, 1994; WANG et al., 2008). Both argue that transportation systems can be complex and that they often include non-linear relations, feedback loops, and delays. Three articles using System Dynamics in the transportation field are analysed to get an overview of the existing models and the knowledge gaps. These studies are also used to get inspiration for the simulation model of this research. Aschauer et al. (2015), describes the interrelationships between logistics and transportation operations in a research paper using a system dynamics approach. Interesting in their system is the link between shipment amount and road kilometers travelled, since this link shows that an increase of the shipment amount leads to a decrease of the road kilometers travelled. This type of link can be used as inspiration in the simulation model development to explain the growth of e-commerce and the small increase of delivery vans and driven kilometers. Another research, from Thaller et al. (2017), focuses on the delivery market in urban areas and presents a model that combines transport and land use. The research illustrates a causal loop diagram including tour characteristics, this loop is quite relevant in this research, since this is part of the complexity of last-mile deliveries, as mentioned in the Logistic paragraph. Both transport models are illustrated with an aggregated view, however transport can be quite discrete and less aggregated than shown in these figures. Supply chains are also part of transport systems, as mentioned earlier. A model

describing a supply chain is therefore also needed to describe the link between capacity needed to deliver all packages and the available logistic capacity. Goncalves and Arango (2010) described in a very simple model the relation between a retailer and a supplier. This is an interesting model as this research attempts to model the link between the packages ordered with e-commerce and the delivery of these packages.

System Dynamics model development

The literature discussed many components that are relevant in this complex system and that all these components impact each other in one way. The SD model simulates the most relevant causal relations and the exogenous variables on these relations, a specification is needed to define these structures. A Causal Loop Diagram (CLD) is used to do so. CLDs can illustrate very clearly the different components and the relations between these components. The variables in a CLD are linked by causal links and can show the possible behaviour of the system. One can identify feedback loops, once the CLD is completed. Feedback loops are often essential in the behaviour of the system as a whole. It is important to identify them and describe them correctly in order to represent the system right. Next to feedback loops, the visualization of the different relations effecting one variable can help to understand the behaviour of that variable (Sterman, 2000). The CLD is based on the literature review, however not all elements mentioned are part of the CLD. Only the most important links found are further illustrated in the CLD, in this case the impact of e-commerce growth on the amount of kilometers driven for last-mile deliveries. The relations in the CLD are further researched and quantified in a simulation model.

The *B2B delivered packages* variable represents the demand for e-commerce, if this variable increases in value, like it does currently, the amount of *Packages ready for shipment* will also increase, which leads to more *Desired operational fleet*. The more capacity is needed in comparison to what is available, the bigger the *Operational fleet gap* is. This brings us to the first feedback loop, *Negative feedback loop fleet size*. This loop illustrates that the bigger the *Operational fleet gap*, the more *New purchased vans* there are, which leads to more *Total operational fleet of vans* and thus a smaller *Operational fleet gap*. In the link from *Operational fleet gap* to *New purchased vans* a delay is found. Purchasing new vans is a big investment and takes time, which causes the delay. An increase of *Total operational fleet of vans* will lead to more *Maximum shipped packages*. This variable also increases with an increase of *Packages ready for shipment* as one can not ship more packages than are physical available. The amount of Shipping packages increases with an increase of *Maximum shipped packages* and decreases the *Packages ready for shipment*, which creates the second and third feedback loop of this CLD. The most right feedback loop, *Negative feedback loop packages*, shows that an increase of e-commerce and thus the amount packages in a DC (*Packages ready for shipment*), leads to more packages that can be shipped (*Maximum shipped packages)* and thus packages that are shipped (*Shipping packages*). The more packages that are shipped, the less packages there are in the DC (*Packages ready for shipment*). Not all packages are successfully delivered in the first try, *Failed delivery*, and have to go back to the DC for a second try, which increase the *Packages ready for shipment*. This rate is currently around 25% *Rate of first time failed delivery*. The first two loops combined create the third feedback loop, also a balancing feedback loop: *Negative feedback loop capacity.* This final loop displays that the more packages are ready for shipment, the more transport capacity is created (*Total operational fleet of vans)*, which leads to more shipments (*Shipping packages*). This first series of blue links in combination with the *Negative feedback loop fleet size*, is based on the Supplier-retailer system in SD from Goncalves and on the the CLD of Aschauer. These blue links, represent the Package supply chain from supply to demand, and is the first subsystem in the SD model. The second sub-system in the SD model is the *Negative feedback loop of fleet size*. The next series of links, the red arrows, is based on the CLD made by Thaller et al. (2017) that illustrates the causal relations between different tour characteristics. These represent the Logistic capacity of the delivery system within the same region of operations' and is the third subsystem in the SD model. The growth of *Packages ready for shipment* leads to an increase of the *Drop factor*. The *Drop factor* is the *amount of packages or stops per kilometer*. The link between e-commerce growth and this so-called *drop factor* was established by assuming that the area stays the same. This *Drop factor* influences three variables, the *Average delivered packages per stop*, the *Average distance between stops* and the *Average delivery time per package* (in the upper left corner of the figure). As mentioned, an increase of e-commerce demand can mean more customers but also more orders per customer. The latter one is represented by the variable Average delivered packages per stop, the first one is represented by the variable Average distance between stops. The *Average delivered packages per stop* has a negative effect on the *Average amount of stops per tour*, since the more packages are delivered at once, the less stops are needed (when the amount of packages in a van stays equal, *Average delivered packages per tour*). A decrease of the *Amount of stops per tour* means a decrease of the time needed to deliver all packages (*Total shipping time per tour*), again in combination with an equal amount of *Average delivered packages per tour*. A decrease of the *Average distance between stops* leads to less *Driving time per tour*, based on an equal amount of packages and the same *Average road speed*. The less *Driving time per tour* is needed, the less *Total shipping time per tour* is needed. Two relations, started at *Drop factor*, show that an increase of e-commerce growth lead to less *Total shipping time per tour*. The third effect of the *Drop factor* is via the *Average deliver time per package*. During a stop, the postmen gets out of his vans, checks the delivery, takes out the needed package and rings the bell to deliver the package. When more packages are delivered per stop, the only thing that changes is taking out the packages, which doesn't take a lot of time. This means that instead of X amount of minutes for one stop, the amount of minutes is split over two packages. This statement is of course based on a simplified reality, but it shows that there is a negative relation between the *Drop factor* and the *Average delivery time per package*. Which also leads to a decrease of the *Total shipping time per tour*. The *Total shipping time per tour* means that a van can make more tours in a day, and thus deliver more packages in a day. A decrease of the *Total shipping time per tour* leads consequently to more *Total operational fleet of vans*. This bring us back to an increase of the amount of shipped packages, the (*Maximum shipped packages*). The last variable, *Km's driven for last-mile delivery*, is the indicator of the amount of kilometers driven for last-mile delivery. The *Km's driven for last-mile delivery* will still increase due to the growth of e-commerce, but probably less steep due to the effect of the *Drop factor* on the *Average amount of stops per tour* and the *Average distance between stops*. The demand from consumers is exogenous represented by the *B2B delivered packages* and the supply of packages is represented by *Shipping packages*. However this link does not influence the demand from the consumers in this closed system, as is the case in the Supply and Demand theory.

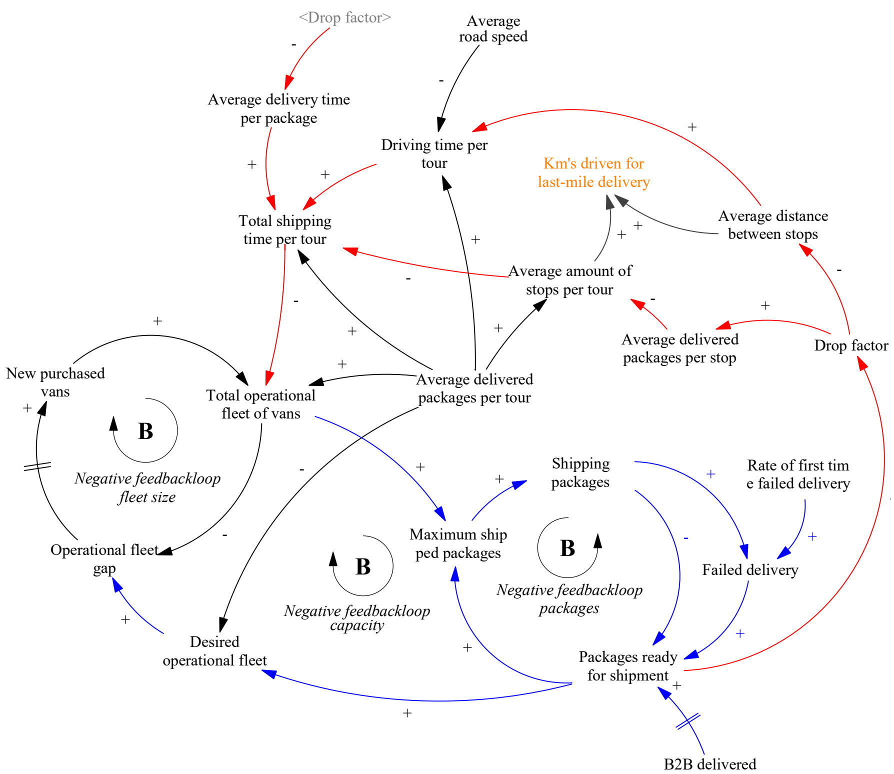


Figure A.3: Causal loop diagram showing the relation of e-commerce demand and the amount of kilometers driven for last-mile delivery

This closed system is mostly active in the freight market and the transport market from the TLM. The Negative feedback loop packages belongs in the freight market and the Negative feedback loop fleet size in the transport market. The red arrows, the links between tour characteristics, belong also in the freight market. The traffic market from the TLM is thus not represented in this CLD and will also not be part of the SD model.

The CLD presented in the previous paragraph forms the basis of the SD model, the set up of the model will be shortly discussed, not the model itself. In a CLD only links and variables are shown, a SD model has a more extensive set-up. The relations and variables are modelled with auxiliary variables, constants, rates, flows and stocks. Accumulation and integration in a simulation model can be modelled with a stock-flow structure. Stocks can be compared with a bath tub, an inflow creates volume in the tub and an outflow can reduce this volume. The stock is thus the integral of the inflow minus the outflow, or the accumulation of the inflow minus the outflow. Every stock has a value at the beginning of the simulation, the initial value. This value can be zero when the height of the accumulation of the stock is important, but the value can also be higher than zero when the changes within the accumulation are important. Only flows can change the state of a stock, and these should be targeted when the state of the stock should be changed.

The simulation model is divided in multiple sub models, the Package flow, the Logistic capacity and the Fleet size. The main literature about SD models was used as inspiration for the relations in this SD model. Also data is needed for the quantification of the relations. The Centraal Bureau voor de Statistiek (CBS) provided data about the size of the e-commerce market (CBS, 2020c) as well as data about logistic characteristics, like the amount of packages per delivery tour, provided by mr. Paul Ras from CBS and via CE Delft (2017).

Simulation model

The negative impacts on the environment and mobility are linked in this research to the total amount of kilometers driven for last-mile deliveries. The more daily kilometers are driven by (conventional) vans, the more pollution and the more traffic. Next to the daily amount of kilometers, the distance per package and the total shipping capacity is evaluated to have a more detailed perspective of the total effect. It can be concluded that the growth of e-commerce does not lead to an equal growth of the amount of kilometers driven for e-commerce. The main reason is that the growth leads to logistic efficiency, like shorter distances between the delivery stops and more packages delivered per stop. The distance per package is decreasing due to the logistic efficiency, this decrease however is asymptotic as there will always be a minimum amount of kilometers to drive from distribution centre to delivery area. The increase of total kilometers, the decrease of distance per package and the increase of total shipping capacity, indicate that there is more transport in total and that more traffic movements are made. This can lead to less traffic safety and more congestion. Which explains that the negative impacts will grow, only not at the same height has the growth of e-commerce.

Strategies

Next, policy strategies are formed and simulated in the SD model. The first strategy implements (unmanned) Pickup points. The use of (unmanned) pick-up points is a known solution and the government has indicated that municipalities could ease the implementation of these points by a standardization of licensing for these points (Ministerie van Economische Zaken en Klimaat, 2020) The second strategy researches the implementation of Light electric freight vehicles (LEFV). Also this strategy is already known, and the government can help with an incentive scheme (Green Deal, 2019) for these vehicles. A closed-loop policy is used for the implementation of both strategies in their own specific SD model.

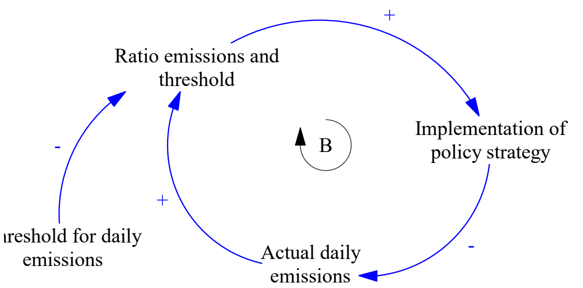


Figure A.4: Implementation of policy strategies

(unmanned) Pick-up points

The strategy mainly influences the amount of first time failed deliveries, since all packages are dropped off at a (unmanned) Pick-up point. The use of Pick-up points in this simulation model resulted in less kilometers driven, less needed vans and less capacity. This is a favourable outcome for the government, since this could mean that there will be less negative impacts on the environment and mobility. The logistic efficiency is even more increased when more consumers can be served by pick-up points. This scenario can best be used in areas with a low drop factor of packages since this will be more profitable for the logistic service provider. More pick-up points also reduces the distance between households and the pick-up points which leads to less passenger transport and makes it more advantageous for consumers to use this option (ACM, 2020).

Light electric freight vehicles

The second strategy simulates the use of light electric freight vehicles (LEFV). LEFV's are simulated with less capacity of packages and with a shorter distance between the distribution centre and the area of deliveries. The vehicles can also use bicycle lanes. This results in more vehicles, more kilometers and a higher distance per package than in the base case. The transport capacity stays equal. This means that more traffic movements are made. However since LEFV's can drive on bicycle lanes, less traffic movements are made on the road, which is beneficial for the traffic safety and congestion. In dense areas, like city centres, this effect is even more relevant. Also less pollution is emitted by the vehicles, as they drive electric.

Also, the combination of both strategies is simultaneously simulated. The strategies complement each other, pick-up points lead to less deliveries and LEFV's lead to less pollution of the deliveries. Due to the set up of the policy implementation (Figure A.4, the strategies are implemented to a lesser extent. The amount of daily emissions is lower and thus less policy is needed to reduce the amount of daily emissions.

Conclusions

E-commerce influences the logistic sector in different ways. The growth of e-commerce leads to more use of transportation, but also results in more logistic efficiency of this transportation. The amount of consumers increases and also the demand per consumer increases. This results in shorter distances between the stops and to more packages delivered per stop, which increases the efficiency of deliveries. This efficiency will however not continue indefinitely and the negative impacts on the environment and mobility will grow continuously. The government can use several instruments on levers within the last-mile delivery system. Van capacity, first time hit rate and the amount of packages delivered at once per stop are the most influential levers within this research scope. This means that the government should look into the available instruments and their influence on these parameters. A campaign to create awareness among citizens to stay home when they expect a package, could for example help to increase the first time hit rate. Using (unmanned) pick-up points leads to less needed shipping capacity, due to the impact on the first time hit rate, and thus less impacts on the environment and mobility. The usage of LEFV's complementary to the use of conventional delivery vans results in less pollution. There will be less traffic movements on the road, but more in total.

Limitations & Further Research

The research give insights in the relation between e-commerce and the amount of kilometers driven for last-mile delivery. However there are also limitations of these insights. The research question is focused on freight transport, however passenger transport is also part of the system. Further research could combine the different transport flows. Next, the urban characteristics of an average city are used in this research and no differentiation is made in e-commerce segments. This can results in excluded gains and losses of the efficiency of last-mile deliveries. Data sets from CBS and ACM do have data on several branches within e-commerce, however not as extensive as the e-commerce segments indicated by CE Delft (2017). A follow-up research could gather more data about e-commerce segments and incorporate different segments in the system. Furthermore, for every vehicle the same amount of packages in the vehicle is assumed. The amount of packages loaded in the van can vary for several reasons. Additionally, the model is quite sensitive to this variable, which makes it an important system boundary. Finally, the amount of kilometers driven for last-mile delivery is used as main indicator for the effect on the environment an mobility in the Netherlands. By translating the amount of kilometers directly to the impact on the environment, a very linear relation is used which does not reflect the whole relation. Further research could add spatial and/or time of day distribution of the transportation's to the research scope. Literature indicated that transportation issues are not the most common field of research for system dynamics, however the reason for this is less indicated. Further research could investigate possible reasons and summarize causes for this event in a literature review. Macro effects and macro behaviour are less represented in the model, like the behaviour of the fleet when new policy is implemented. Further research could focus on macro behaviour and build a model that simulates the dynamics between e-commerce and the logistic sector on a more aggregated level.

B
Conceptual Model

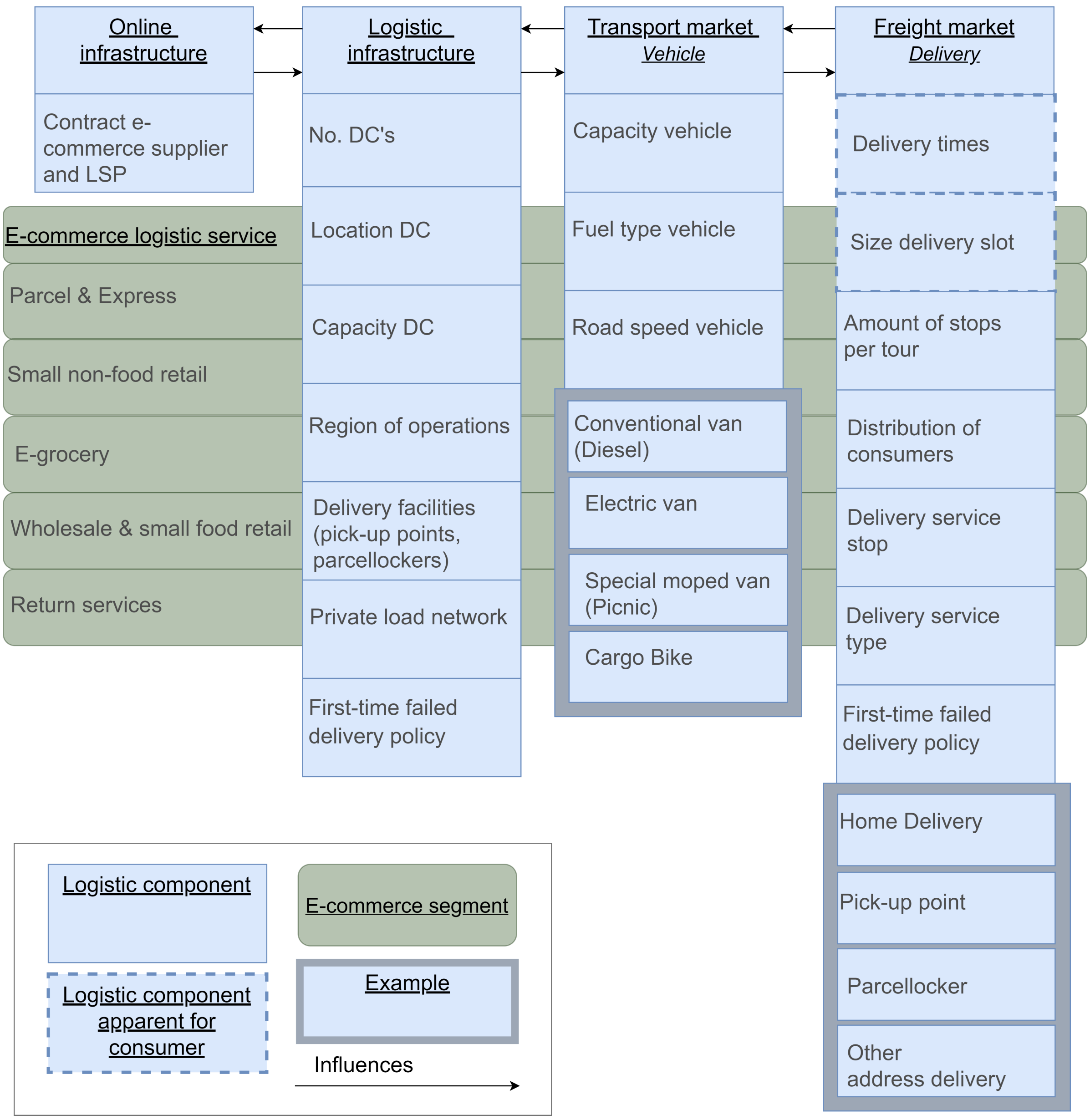


Figure B.1: Conceptual model including Transport Layer Model, excluding Supply & Demand, Factors, Developments and Government Instruments

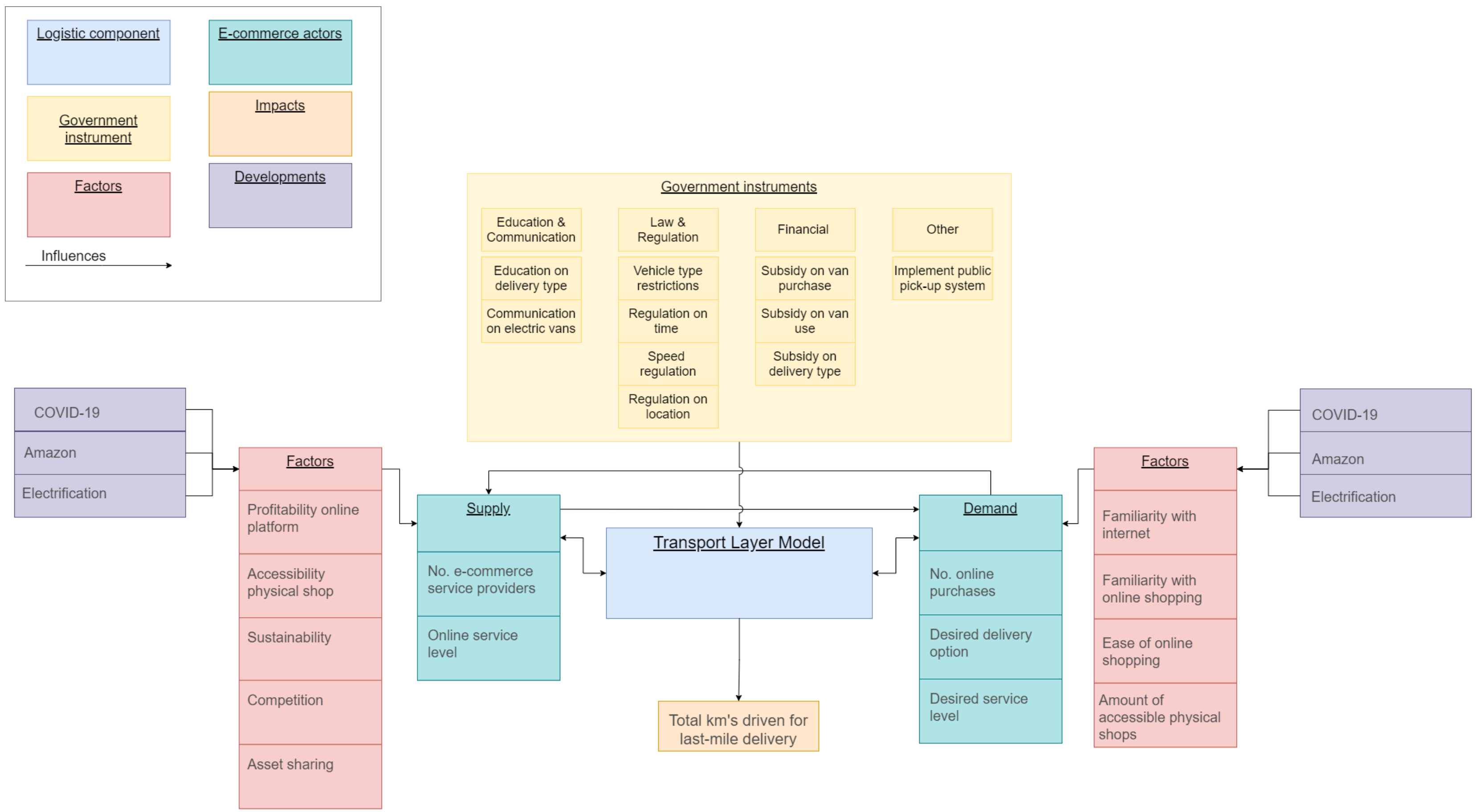


Figure B.2: Conceptual model including Supply & Demand, Factors, Developments and Government Instruments, excluding Transport Layer Model

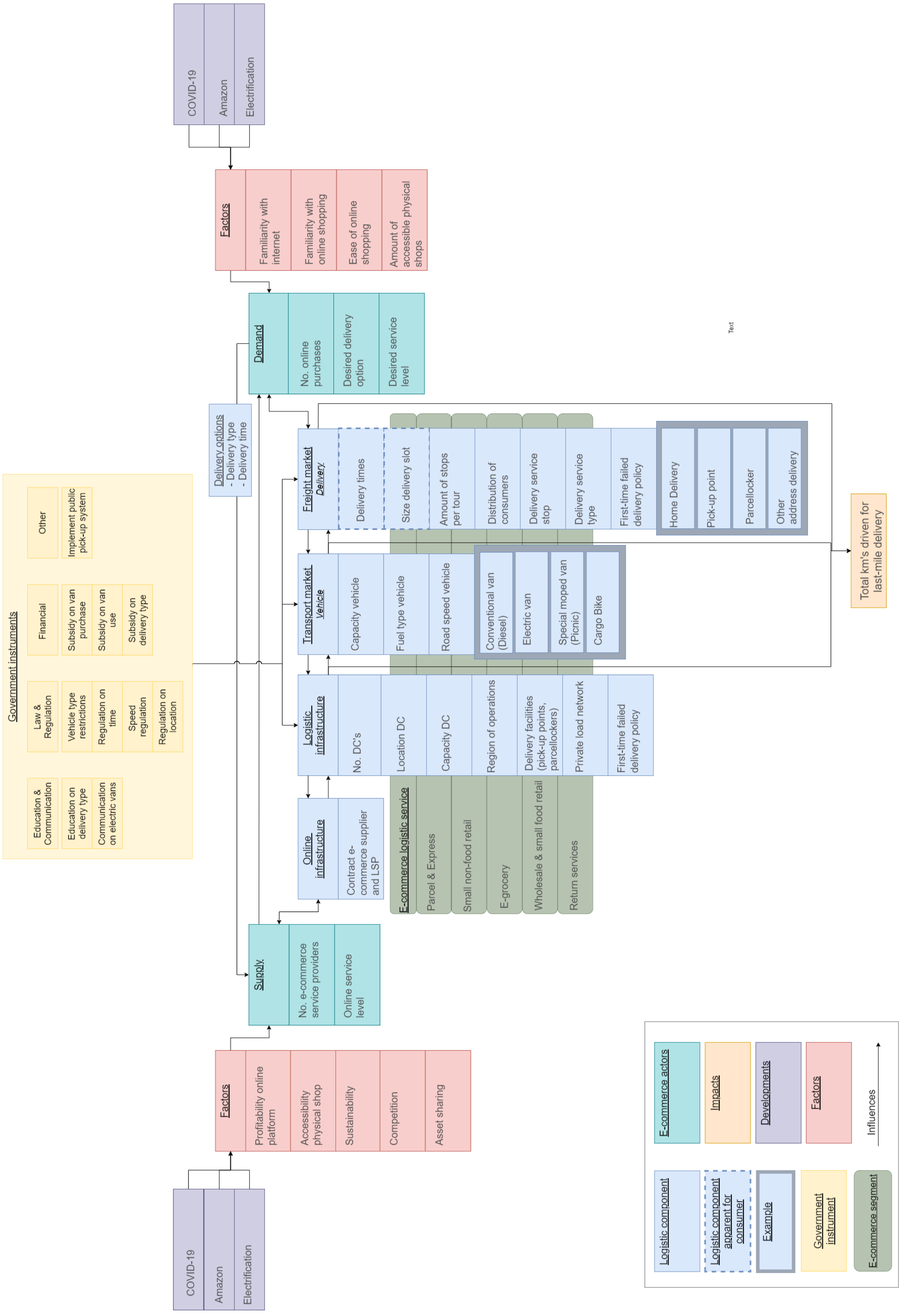


Figure B.3: Conceptual model

C

Variables in simulation model

Table C.1: External parameters A-I

External parameter	Unit	Initial Value	Source
Adaptivity tours	Day	1	N.A.
Accepted margin for fleet gap	Dmnl	0.1	N.A.
Adaptivity tours	Day	1	N.A.
Average road speed	Km/ Hour	25	Peters (2012)
Base distance from DC to neighbourhood	Km/(Tour*Van)	30	Expert
Bundeling time	Day	0,75	N.A.
”CO2 per KM”	CO2/ Km	0,3	CE Delft (2017)
Effective daily available delivery hours	Hour/ Van/ Day	6	N.A.
Fraction	1/ Day	0,0003872	N.A.
Hour per day	Hour/ Day	24	N.A.
Initial package delivery time	Minute/Package	4	Schonewille (2015)
Initial packages per stop	Package/Stop	1.3	CBS data
Initial stops per km	Stop/ Km	2	CBS data
Initial value B2B delivered packages	Package/ Day	770000	N.A.
Initial value failed shipments	Package	200000	N.A.
Initial value fleet	Van	20000	N.A.
Initial value packages	Package	5,78E+05	N.A.
Initial value ready packages	Package	825000	N.A.
Initial value sorted packages	Package	742500	N.A.
Initial value tours per day	Tour/ Day	1	N.A.

Table C.2: External parameters L-Z

External parameter	Unit	Initial Value	Source
Lifetime van	Day	3000	CE Delft (2017)
Minutes per hour	Minute/ Hour	60	N.A.
Normal decline fraction	1/ Day	0,0003872	ACM (2020), Roland Berger (2017)
(unmanned) Pick-up point effect on rate	Dmnl	0,2	ACM (2020)
Purchasing time	Day	90	N.A.
Return rate	Dmnl	0,4	Thuiswinkel (2020b)
Return time	Day	1	N.A.
Sorting time	Day	0,75	N.A.
Target shipping time	Day	0,85	N.A.
Total size of retail market	Package/ Day	7700000	ACM
Van capacity in packages	Package/ Van	40	CE Delft (2017)
Vans per Tour	1/ Tour	1	N.A.
Yearly amount of delivery days	Day/ Year	310	CE Delft (2017)

Table C.3: Internal integral variables A-Z

Internal variable	Unit	Initial Value	Source code Vensim
Delivered packages	*Package*	*0*	*INTEG (Succesfull delivery,)*
"E-commerce growth"	*Package/ Day*	*Initial value B2B delivered packages*	*INTEG (Increase of growth-Decline of growth)*
Entered packages in DC	*Package*	*Initial value packages*	*INTEG (B2B delivered packages-Sorting packages)*
Failed shipments	*Package*	*Initial value failed shipments*	*INTEG (Failed delivery-Back to DC)*
Packages ready for shipment	*Package*	*Initial value packages*	*INTEG (Bundeling packages-Shipping packages,)*
Planned new vehicles	*Van*	*0*	*INTEG (Change in planning)*
Sorted packages in DC	*Package*	*Initial value sorted packages*	*INTEG ((Second try packages+Sorting packages)-Bundeling packages)*
Total operational fleet of vans	*Van*	*Initial value fleet*	*INTEG (New vans-Discarded vans)*
Tours per day	*Tour/Day*	*Initial value tours per day*	*INTEG(Change in tours per day)*

Table C.4: Internal variable A-E

Internal variable	Unit	Initial Value	Source code Vensim
Accepted operational fleet gap	Van		Accepted margin for fleet gap*Total operational fleet of vehicles
Available operational fleet	Van/Day		Total fleet of vans/Actual shipping time
Average amount of stops per tour	Stop/(Van*Tour)		Packages delivered per tour/Average delivered packages per stop
Average delivered packages per stop	Package/ Stop		Initial packages per stop+Effect growth on packages per stop
B2B delivered packages	Package/ Day		Growth B2B delivered packages
Back to DC	Package/Day		Failed shipments/Return time
Bundeling packages	Package/Day		Sorted packages in DC /Bundeling time
Change in tours per day	Tour/(Day*Day)		Difference in tours per day/Adaptivity tours
Change in planning	Van/ Day		Vehicles needed/Planning time
Change in distance per package	Km/ (Day*Package)		(New distance per package-Distance per package by van)/Daily km
Daily amount of tours per van	Tour/(Day*Van)		Daily available delivery hours/Time per tour
Daily extra km's due first time failed	Km/Day		Failed delivery*Distance per package
Daily extra emissions	CO2/Day		Daily extra due failure kilometers*"CO2 per KM"
Daily last-mile emissions	CO2/Day		"CO2 per KM"*Daily successful kilometers
Daily successful last-mile km's driven	Km/Day		Successful delivery*Distance per package
Decline of growth	Package/ (Day*Day)		"E-commerce growth"*Decline fraction
Decline fraction	1/ Day		Normal decline fraction*Effect of product life cycle
Desired fleet size	Van*Day		Packages ready for shipment/(Packages delivered per tour*Tours per day)
Desired operational fleet	Van		Desired fleet size/Target shipping time
Difference in tours per day	Tour/Day		MAX(0, Max amount of tours per day-Tours per day)
Discarded vans	Van/Day		Total operational fleet of vans/Lifetime van
Distance between stops	Km/ Stop		1/Effect growth on distance between stops
Distance per tour	Km/(Van*Tour)		Base distance from DC to neighborhood+Distance between stops*Average amount of stops per tour
Effect growth on distance between stops	Km/ Stop		Initial stops per km+Initial stops per km*Growth packages
Effect growth on package delivery time	Minute/ Package		Initial package delivery time*Growth packages

Table C.5: Internal variable E-Z

Internal variable	Unit	Initial Value	Source code Vensim
Effect growth on package per stop	Package/ Stop		Initial packages per stop*Growth packages
Effect of product life cycle	1		”E-commerce growth”/Total size of market
Failed delivery	Package/Day		Shipping packages*Rate of first time failed
Growth packages	1		(Entered packages in DC-Initial value packages)/Initial value packages
Increase of growth	Package/ (Day*Day)		Fraction*”E-commerce growth”
Max amount of tours per day	Tour/Day		Daily available delivery hours/Time per tour
Max outflow DC	Package/Day		MAX(0, Packages ready for shipment/Target shipping time)
Maximum shipping capacity	Package/Day		MAX(0, MIN(Total shipping capacity,Max outflow DC))
New vans	Van/Day		Operational fleet gap/Purchasing time
Operational fleet gap	Van		Desired operational fleet- (Total operational fleet of vehicles + Planned new vehicles)
Package delivery time	Minute/ Package		Initial package delivery time/Average delivered packages per stop
Packages delivered per tour	Package/ (Van*Tour)		Van capacity in packages*Van per tour
Rate of first time failed	Dmnl		0.25 - (unmanned) Pick-up point effect on rate
Return shipments	*Package*	*0*	*INTEG (Returning)*
Returning	Package/Day		Shipping packages*Return rate
Second try packages	Package/Day		Back to DC
Shipped packages	*Package*	*0*	*INTEG (Shipping packages,)*
Shipping packages	Package /Day		Maximum shipping capacity
Sorting packages	Package/ Day		Entered packages in DC/Sorting time
Succesfull delivery	Package/Day		Shipping packages*(1-Rate of first time failed)
Time per tour	Hour/ (Van*Tour)		Total driving time per tour+Total package delivery time per tour
Total driving time per tour	Hour/ (Van*Tour)		Distance per tour/Average road speed
Total package delivery time per tour	Hour/ (Van*Tour)		(Packages delivered per tour*Package delivery time) / Minutes per hour
Total shipping capacity	Package/Day		Packages delivered per tour*Tours per day* Total operational fleet of vans
Vehicles needed	Van		Operational fleet gap-Accepted operational fleet gap

Table C.6: Output variables A-Z

Output	**Unit**	**Initial value**	**Source code Vensim**
Actual shipping time	Day		Packages ready for shipment/Shipping packages
Distance driven for last-mile delivery	*Km*	*0*	*INTEG ("Daily succesfull last-mile km's driven"+Daily extra km's due first time failed)*
Distance per package	*Km/Package*	*1,25*	*INTEG(Change in distance per package)*
Planned shipping time	Day/ (Van*Tour)		Time per tour/Hour per day
Roadmileage per year per van	Km/ (Van *Year)		Distance per tour*Tours per day*Yearly amount of delivery days
Total emissions by last-mile delivery	*CO2*	*0*	*INTEG("Daily last-mile emissions"+Extra CO2)*
Total shipping capacity	Package/ Day		Packages delivered per tour*Tours per day* Total operational fleet of vans

D

Overview of policy levers in Logsitic Capacity

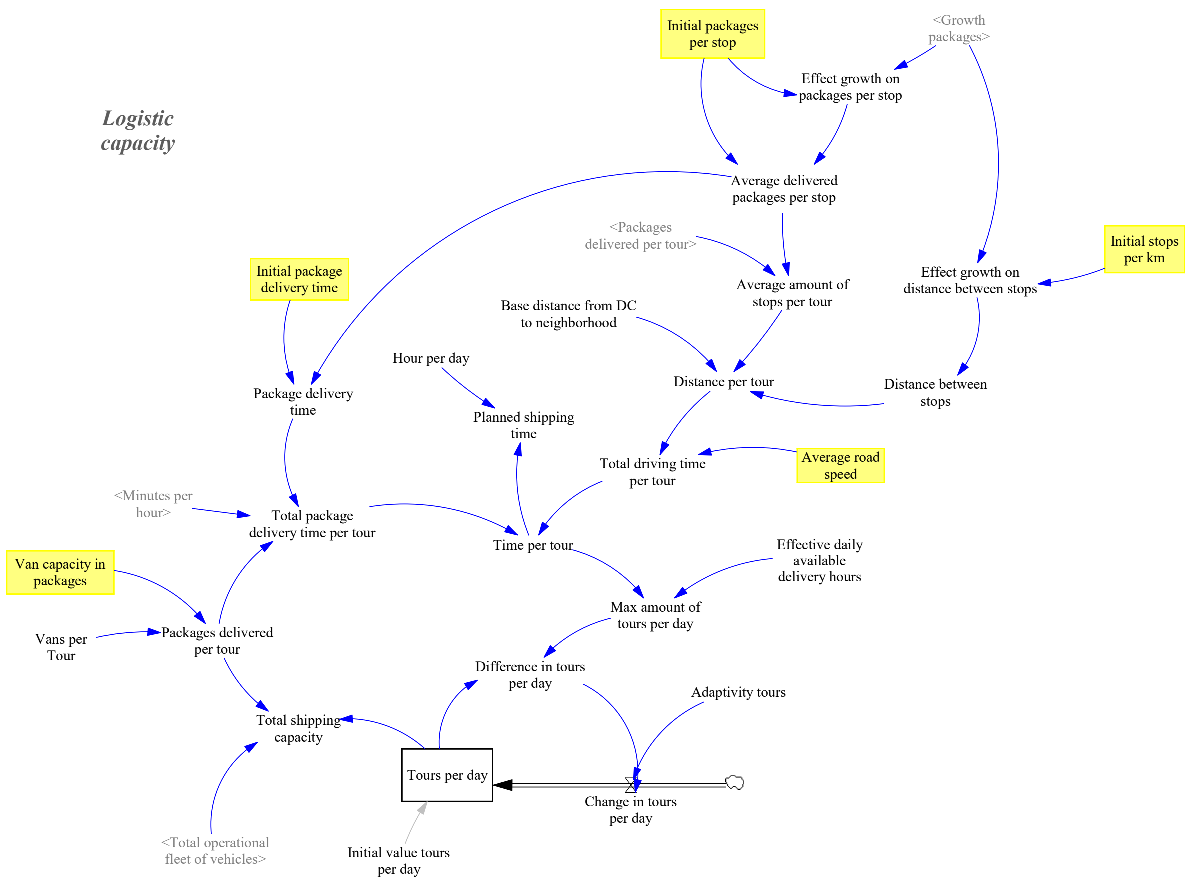


Figure D.1: Logistic capacity sub system including marked policy levers in yellow

E

Verification & Validation

1. Parameter-verification test
2. Extreme-condition test
3. Behaviour-sensitivity test

E.1. Parameter-verification test

Table E.1: Bandwidth parameters for verification test

External parameter	Unit	Initial Value	Bandwidth test	Source
Van capacity in packages	Packages/ Van	40	20-50	CBS data
Average road speed	Km/ Hour	25	18 - 32	(Peters, 2012)
Fraction for growth B2B delivered packages	1/ Day	0.0003872	0.0003 - 0.00046	(ACM, 2020; Roland Berger, 2017)
Initial stops per km	Stop/ Km	2	1.25 - 4	CBS data
Initial package delivery time	Minute/ Package	4	3 - 6	(Schonewille, 2015)

Parameter-verification test: Van capacity in packages

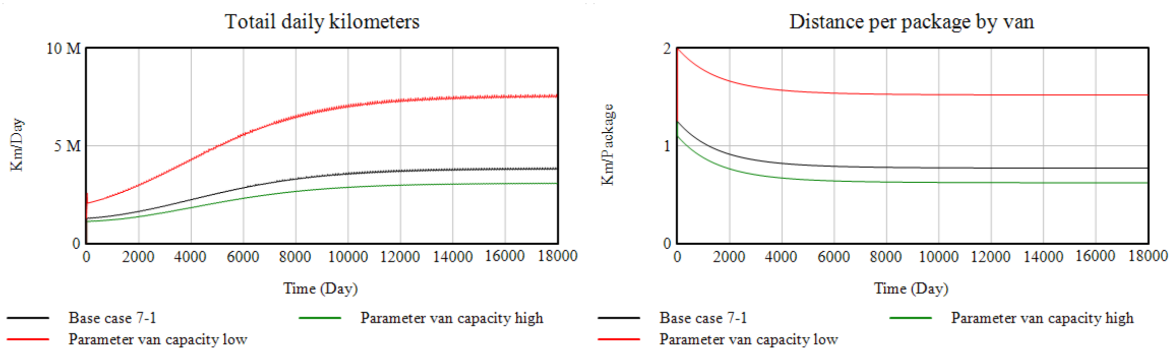


Figure E.1: Parameter-verification test by *Van capacity in packages* part 1

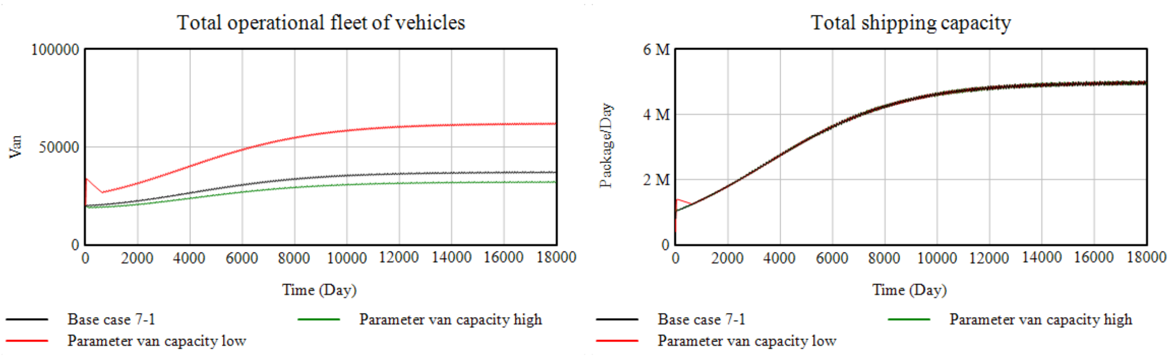


Figure E.2: Parameter-verification test of *Van capacity in packages* part 2

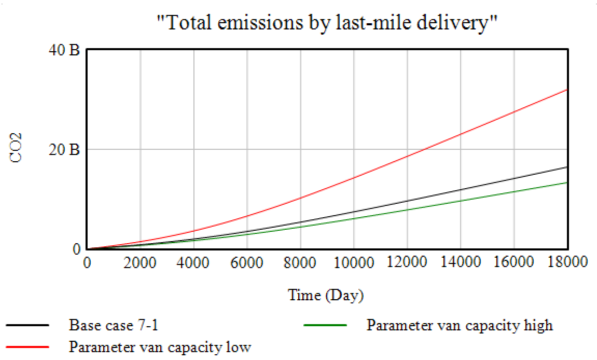


Figure E.3: Parameter-verification test of *Van capacity in packages* part 3

Parameter-verification test: Average road speed

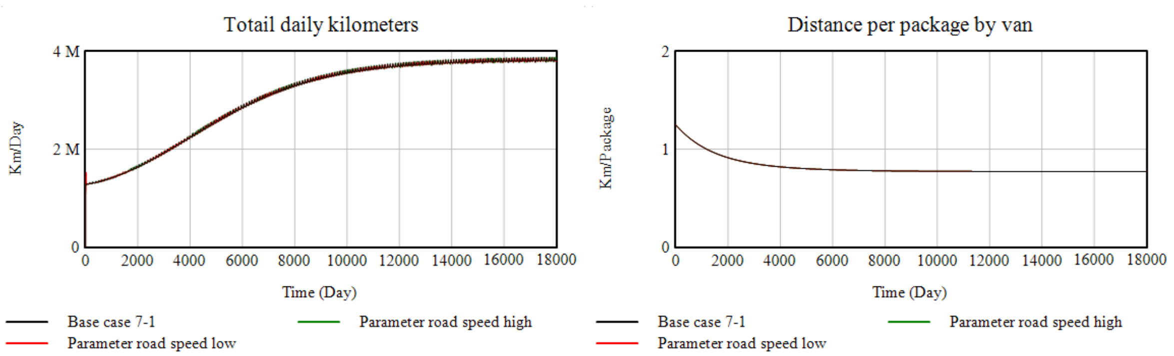


Figure E.4: Parameter-verification test by *Average road speed* part 1

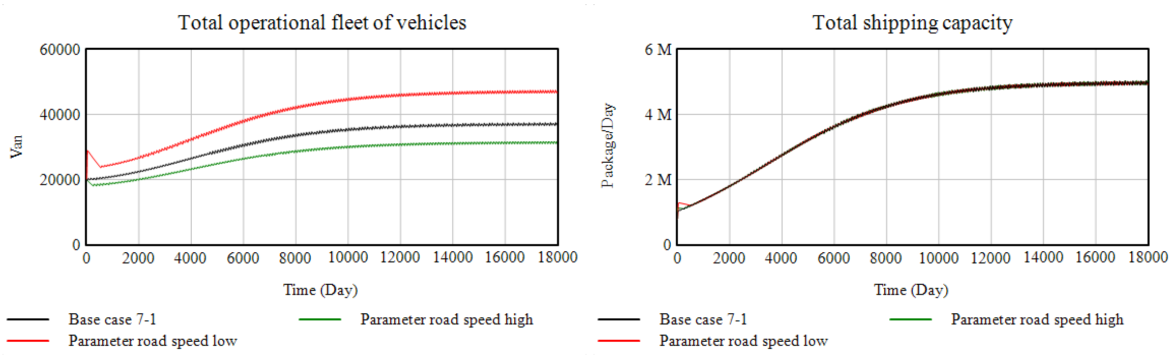


Figure E.5: Parameter-verification test of *Average road speed* part 2

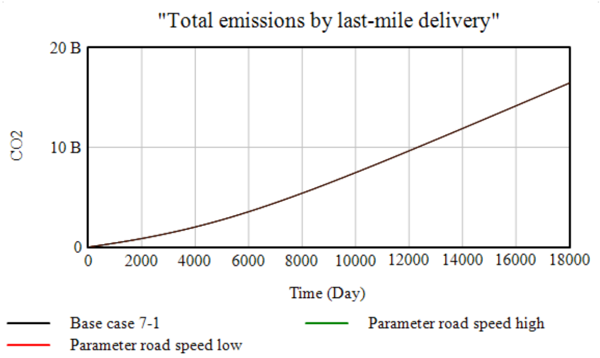


Figure E.6: Parameter-verification test of *Average road speed* part 3

Parameter-verification test: E-commerce growth

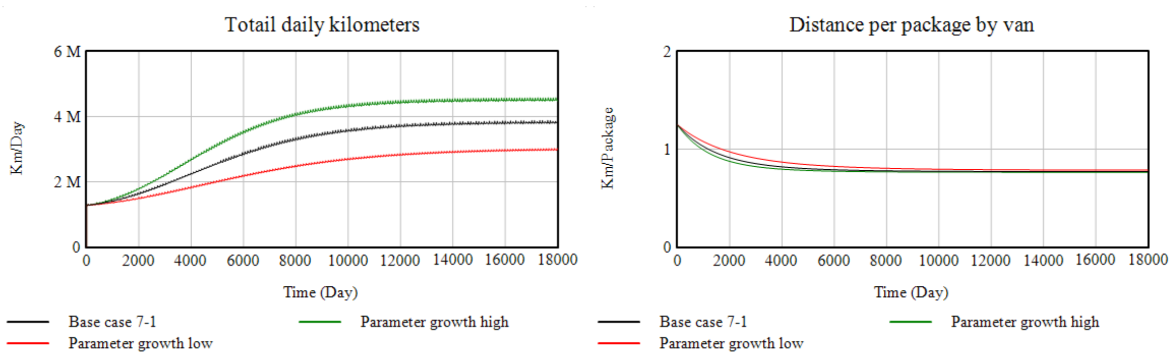


Figure E.7: Parameter-verification test by *E-commerce growth* part 1

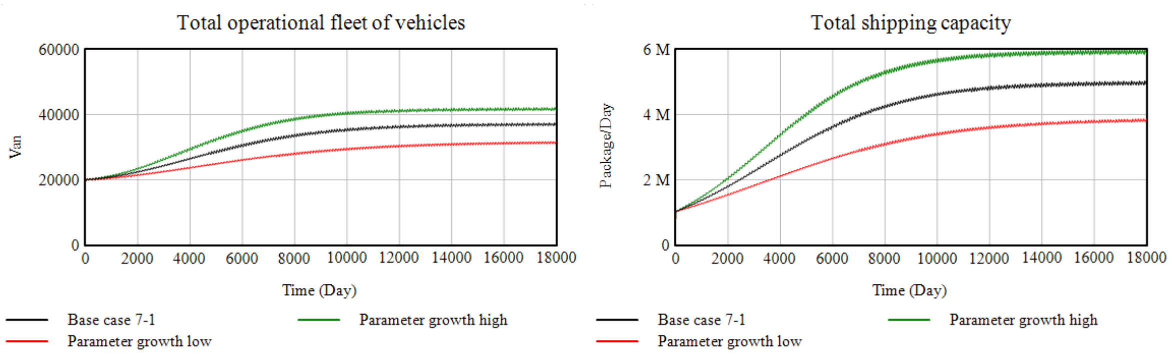


Figure E.8: Parameter-verification test of *E-commerce growth* part 2

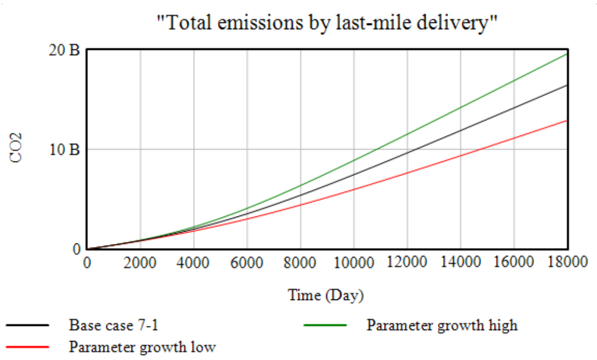


Figure E.9: Parameter-verification test of *E-commerce growth* part 3

Parameter-verification test: Initial stops per kilometer

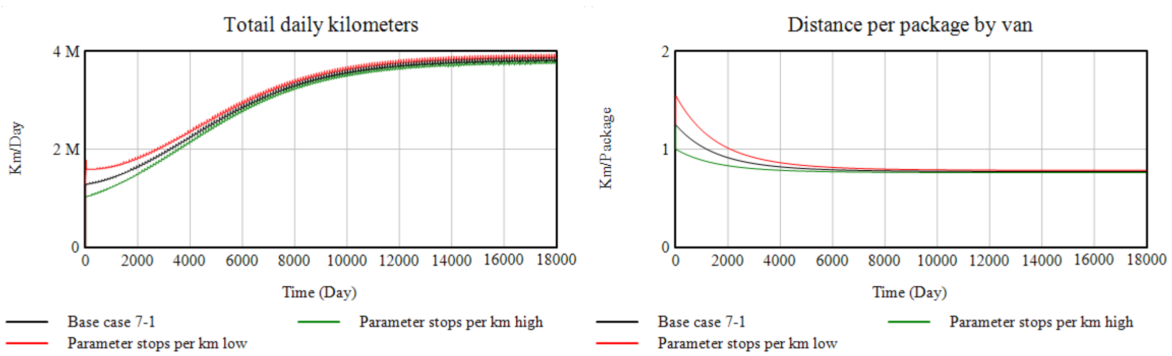


Figure E.10: Parameter-verification test by *Initial stops per kilometer* part 1

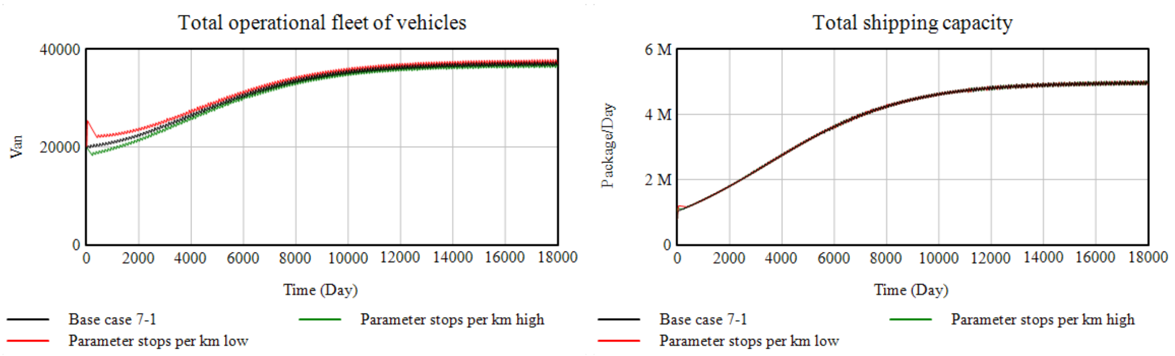


Figure E.11: Parameter-verification test of *Initial stops per kilometer* part 2

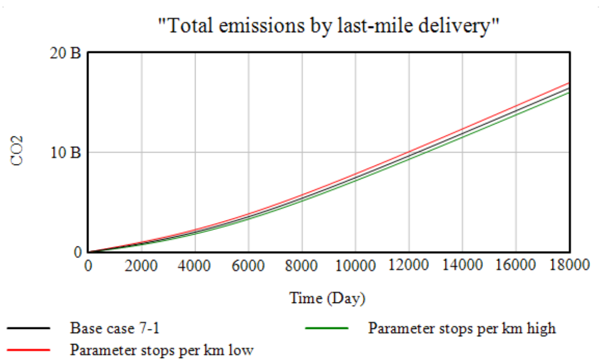


Figure E.12: Parameter-verification test of *Initial stops per kilometer* part 3

Parameter-verification test: Package delivery time

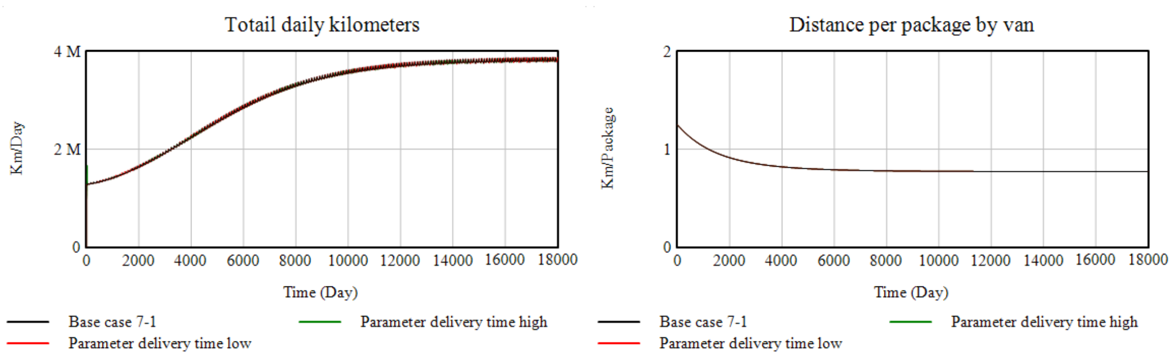
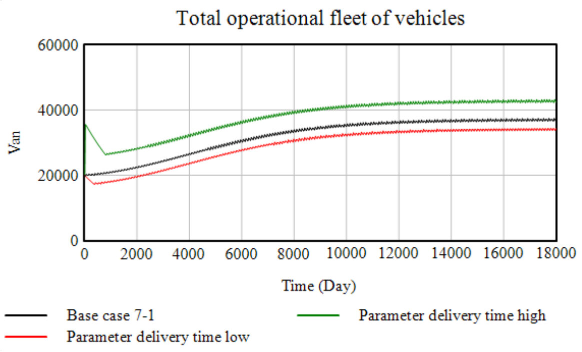


Figure E.13: Parameter-verification test by *Package delivery time* part 1



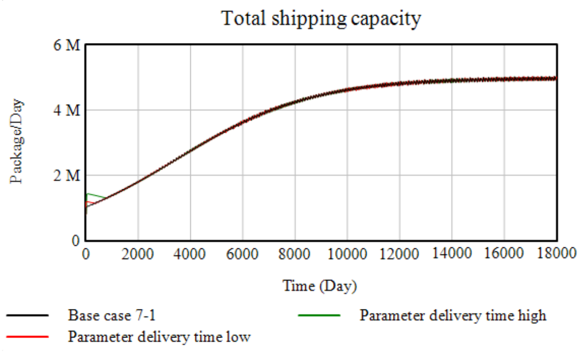


Figure E.14: Parameter-verification test of *Package delivery time* part 2

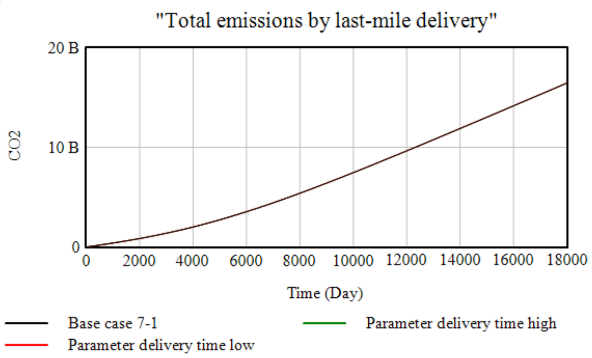
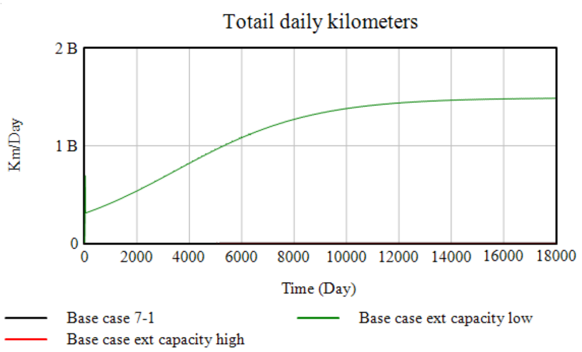


Figure E.15: Parameter-verification test of *Package delivery time* part 3

E.2. Extreme-condition test

1. Van capacity in packages
2. E-commerce growth
3. Package delivery time

Extreme-condition test: Van capacity



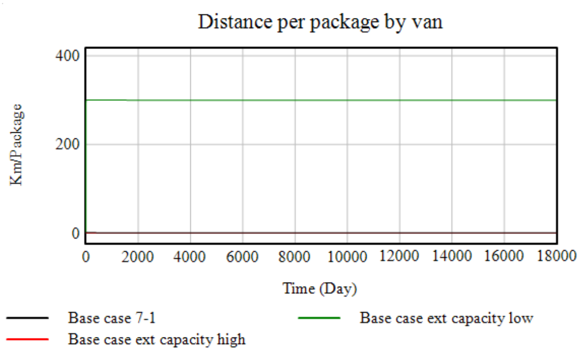


Figure E.16: Extreme-condition test by *Van capacity in packages* part 1

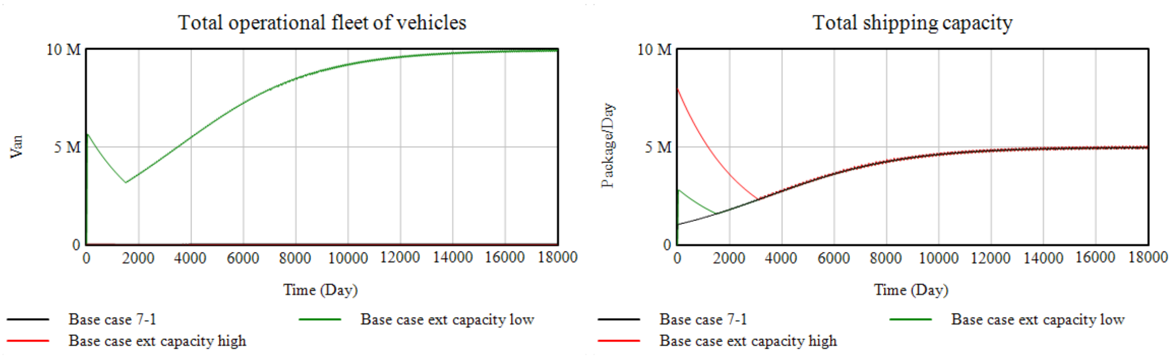


Figure E.17: Extreme-condition test of *Van capacity in packages* part 2

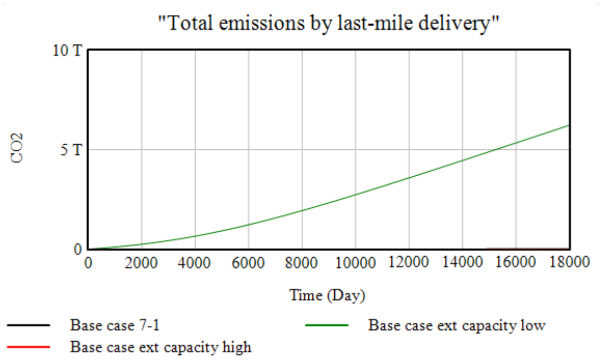


Figure E.18: Extreme-condition test of *Van capacity in packages* part 3

Extreme-condition test: E-commerce growth

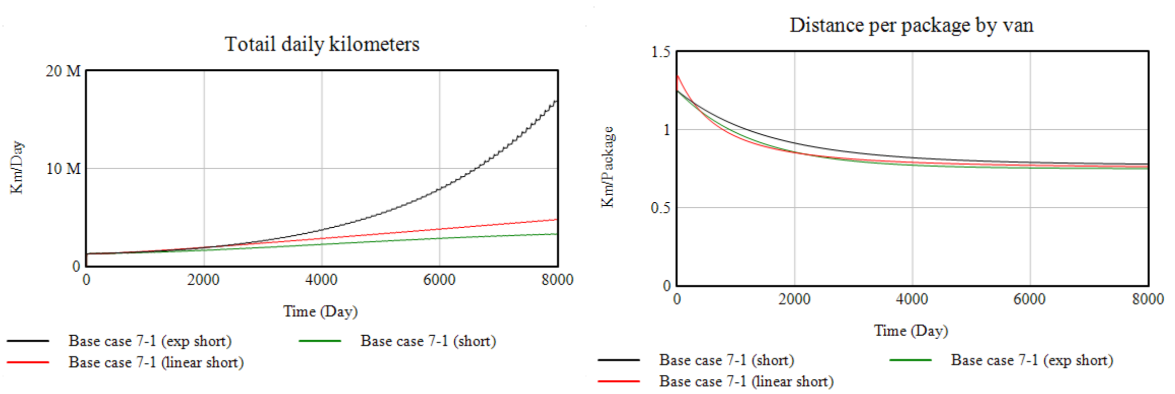


Figure E.19: Extreme-condition test by *E-commerce growth* part 1

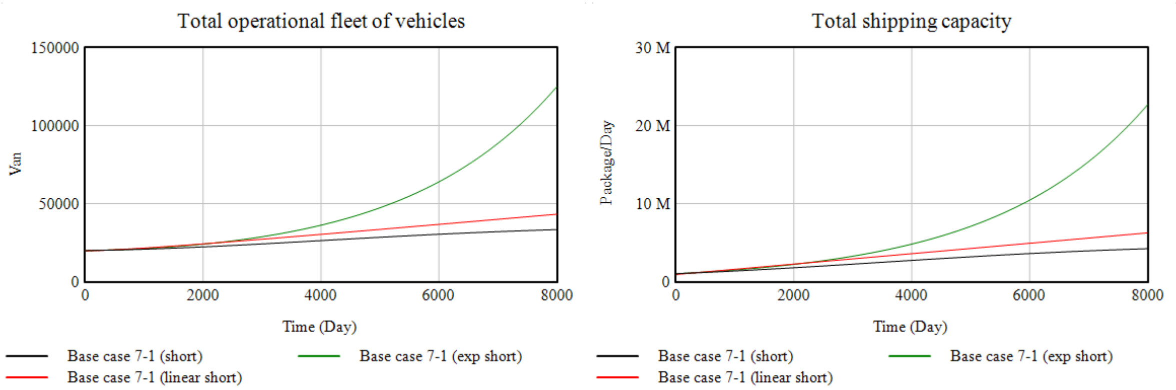


Figure E.20: Extreme-condition test of *E-commerce growth* part 2

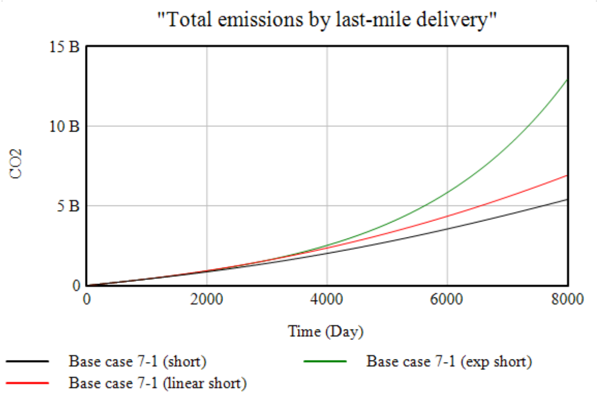


Figure E.21: Extreme-condition test of *E-commerce growth* part 3

Extreme-condition test: Package delivery time

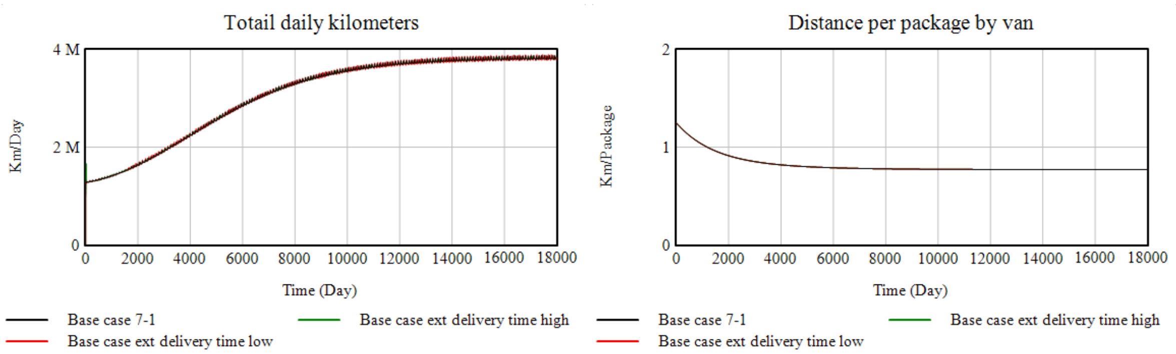


Figure E.22: Extreme-condition test by *Package delivery time* part 1

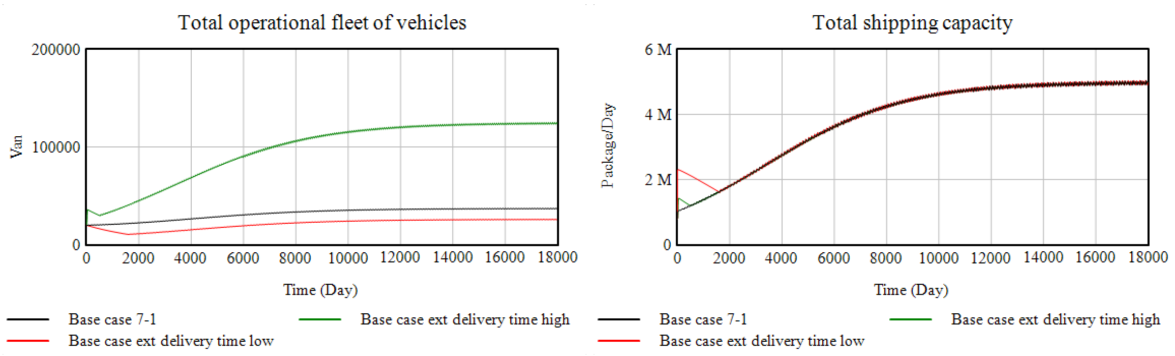


Figure E.23: Extreme-condition test of *Package delivery time* part 2

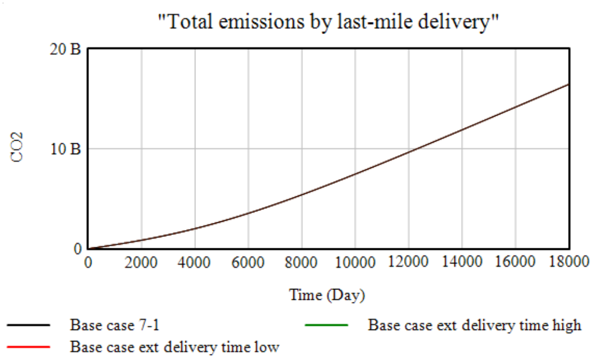


Figure E.24: Extreme-condition test of *Package delivery time* part 3

E.3. Behaviour-sensitivity test

1. Van capacity in packages
2. Rate of first time failed delivery
3. Average road speed
4. Average delivered packages per stop
5. Initial stops per kilometer
6. Package delivery time

Behaviour-sensitivity test: Van capacity in packages

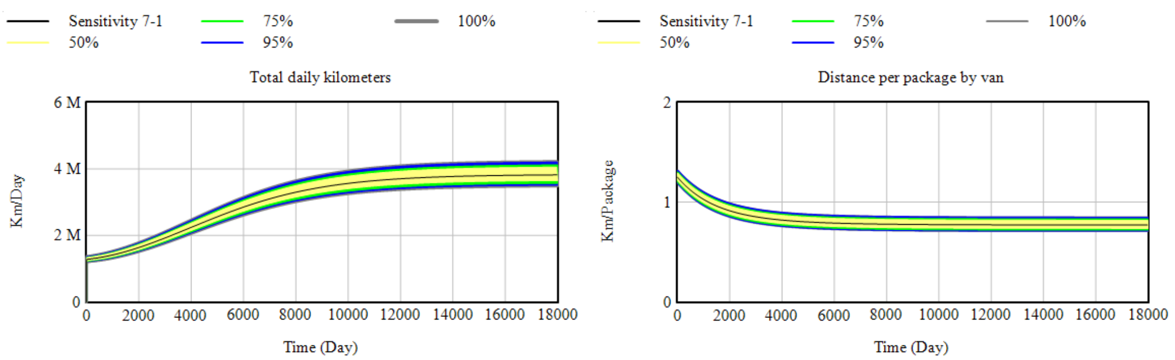


Figure E.25: Behaviour-sensitivity test by *Van capacity in packages* part 1

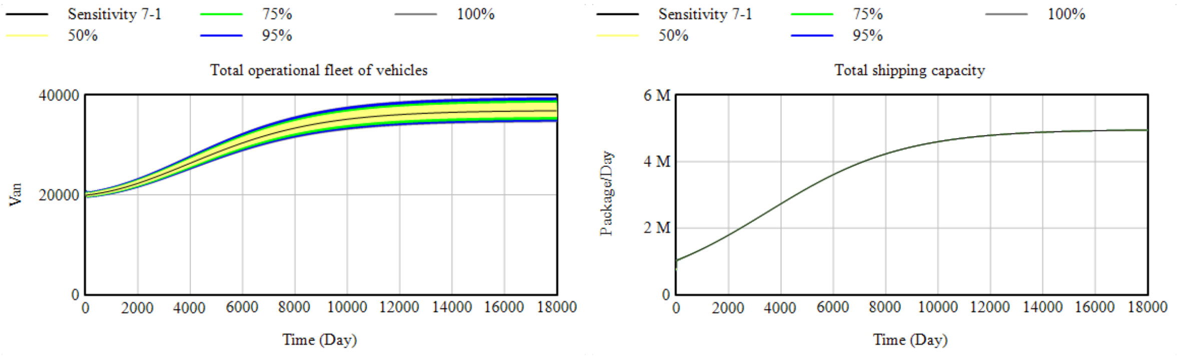


Figure E.26: Behaviour-sensitivity test of *Van capacity in packages* part 2

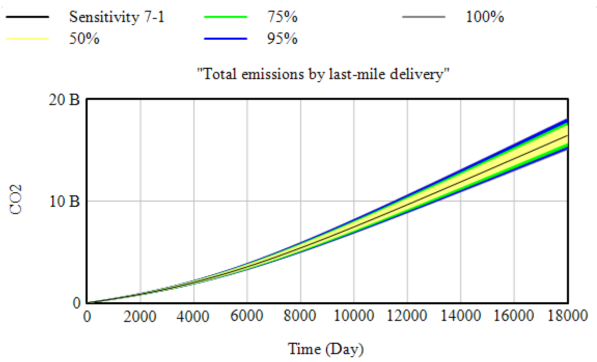


Figure E.27: Behaviour-sensitivity test of *Van capacity in packages* part 3

Behaviour-sensitivity test: Rate first time failed delivery

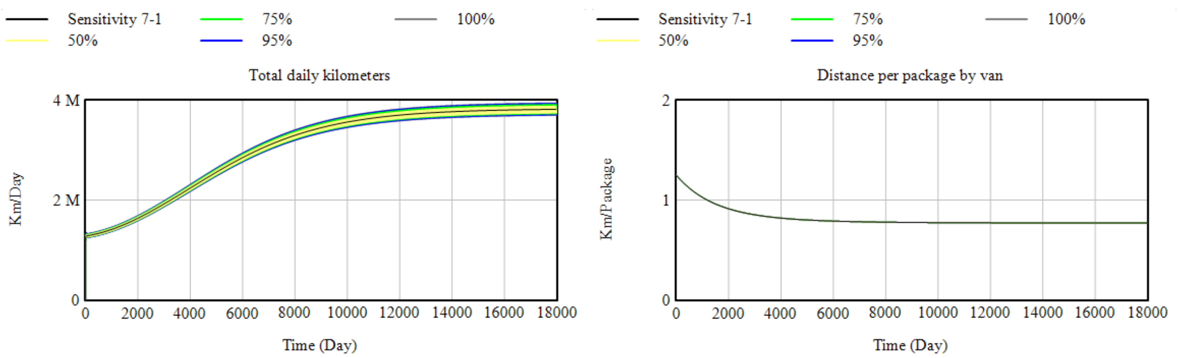


Figure E.28: Behaviour-sensitivity test by *Rate first time failed delivery* part 1

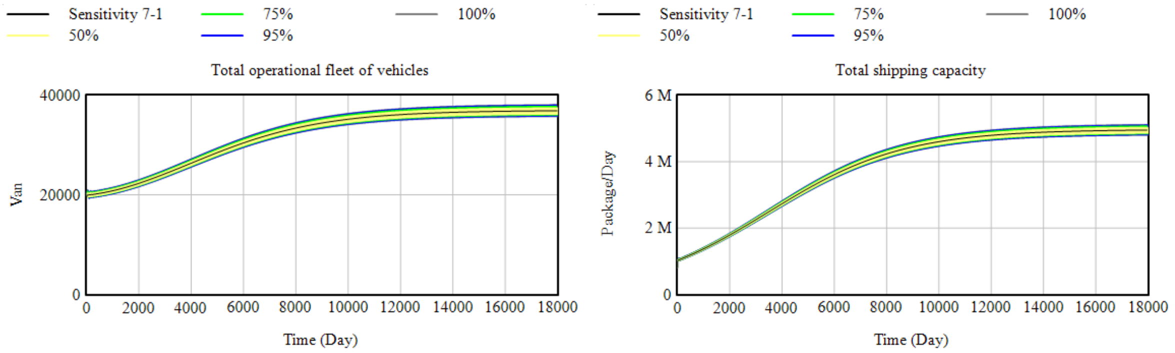


Figure E.29: Behaviour-sensitivity test of *Rate first time failed delivery* part 2

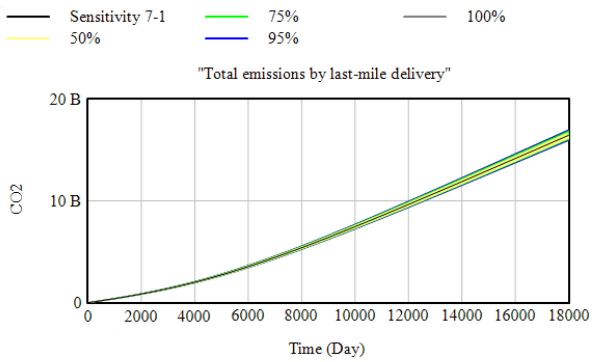


Figure E.30: Behaviour-sensitivity test of *Rate first time failed delivery* part 3

Behaviour-sensitivity test: Average road speed

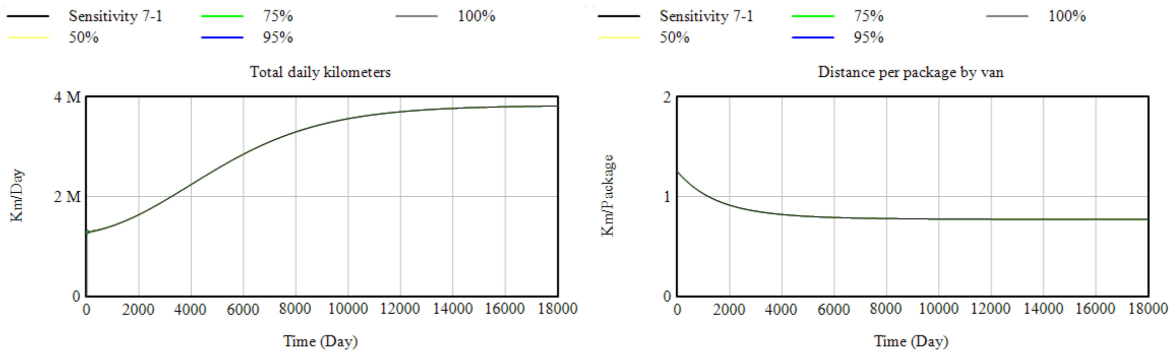


Figure E.31: Behaviour-sensitivity test by *Average road speed* part 1

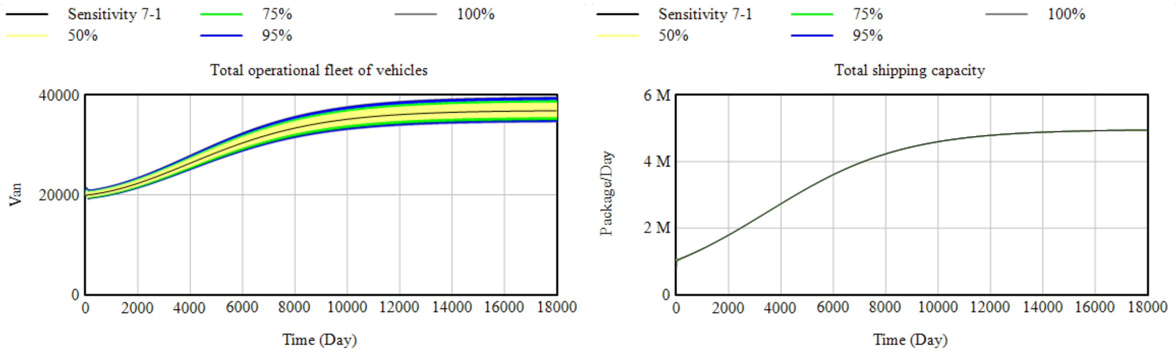


Figure E.32: Behaviour-sensitivity test of *Average road speed* part 2

Figure E.33: Behaviour-sensitivity test of *Average road speed* part 3

Behaviour-sensitivity test: Average delivered packages per stop

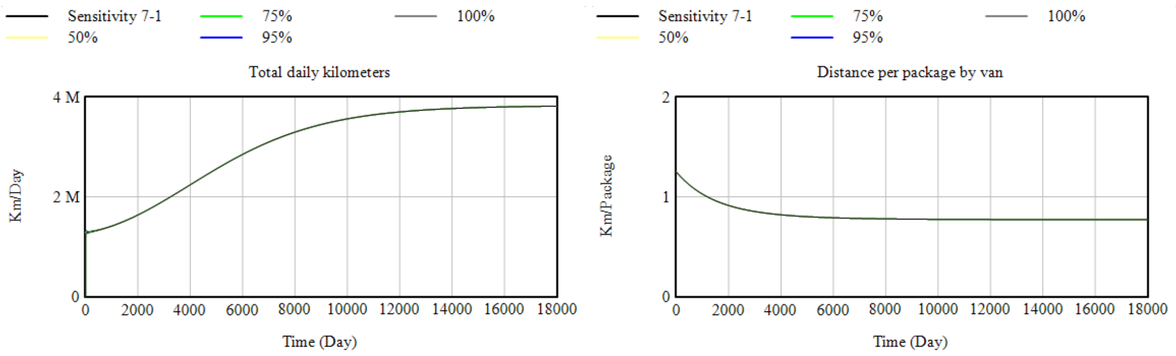


Figure E.34: Behaviour-sensitivity test by *Average delivered packages per stop* part 1

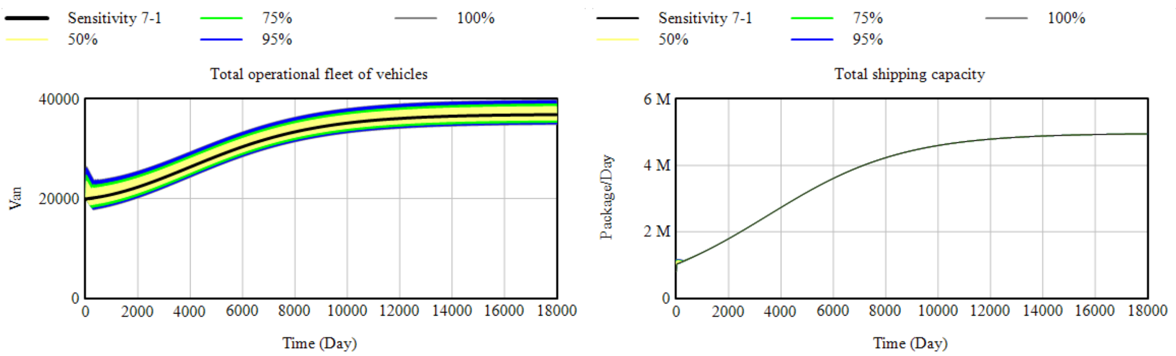


Figure E.35: Behaviour-sensitivity test of *Average delivered packages per stop* part 2

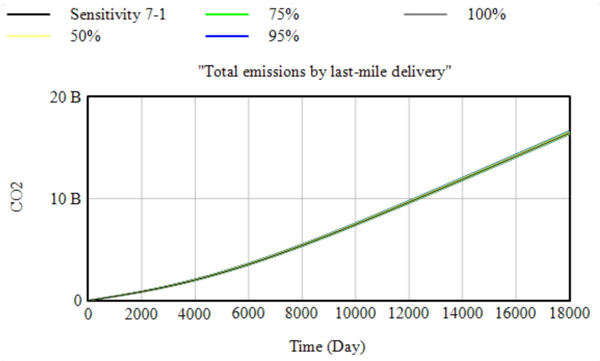


Figure E.36: Behaviour-sensitivity test of *Average delivered packages per stop* part 3

Behaviour-sensitivity test: Initial stops per kilometer

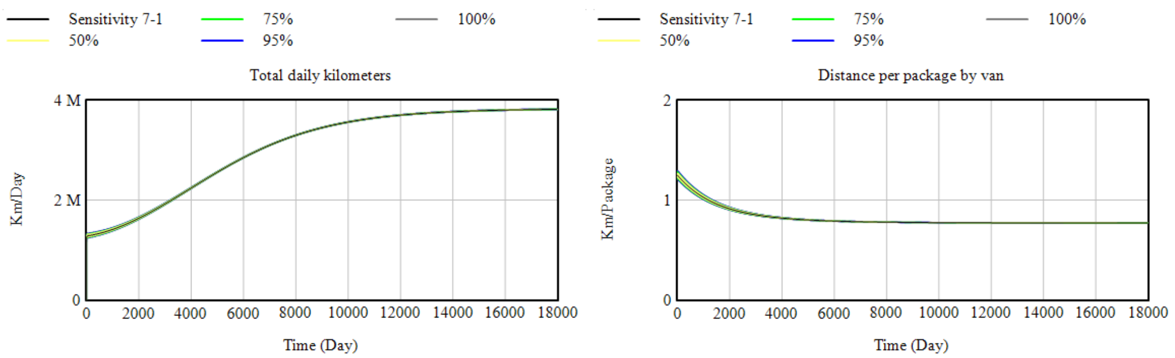


Figure E.37: Behaviour-sensitivity test by *Initial stops per kilometer* part 1

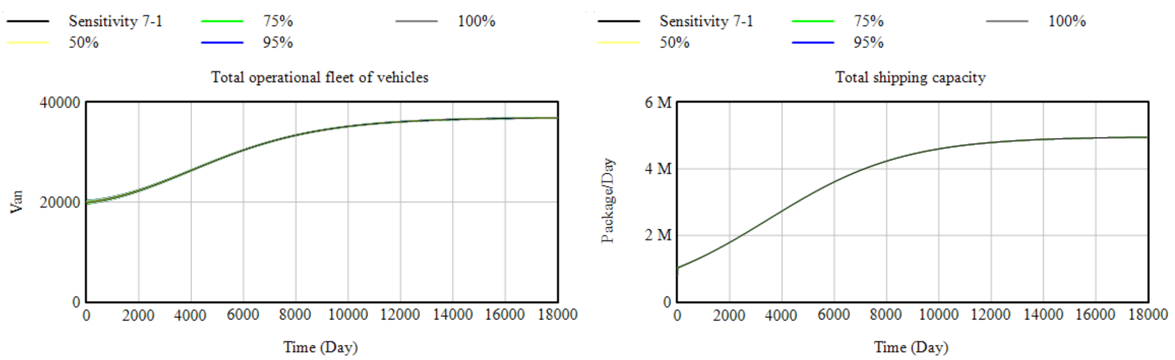


Figure E.38: Behaviour-sensitivity test of *Initial stops per kilometer* part 2

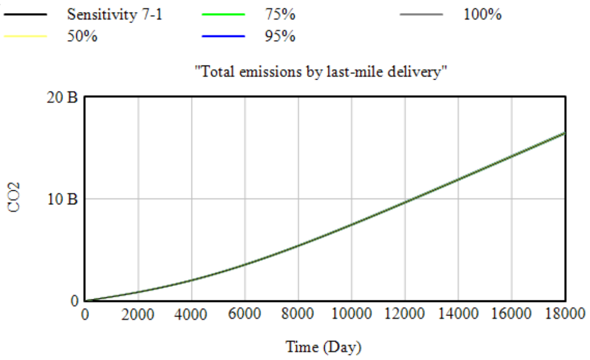


Figure E.39: Behaviour-sensitivity test of *Initial stops per kilometer* part 3

Behaviour-sensitivity test: Package delivery time

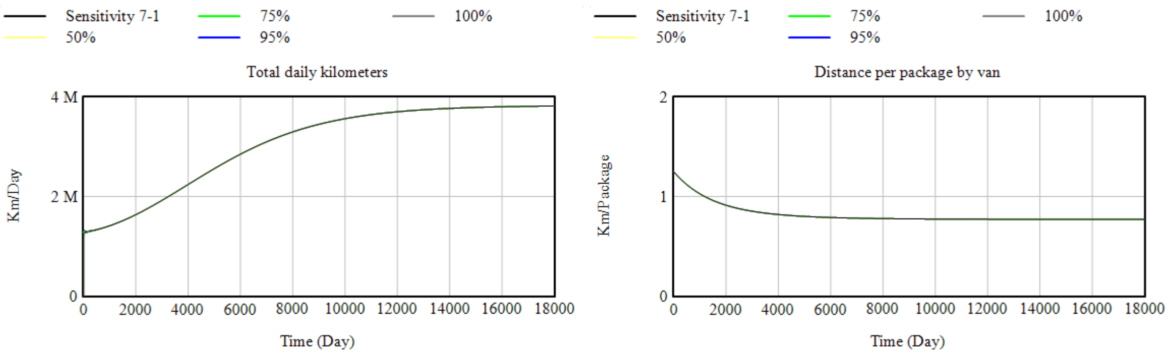


Figure E.40: Behaviour-sensitivity test by *Package delivery time* part 1

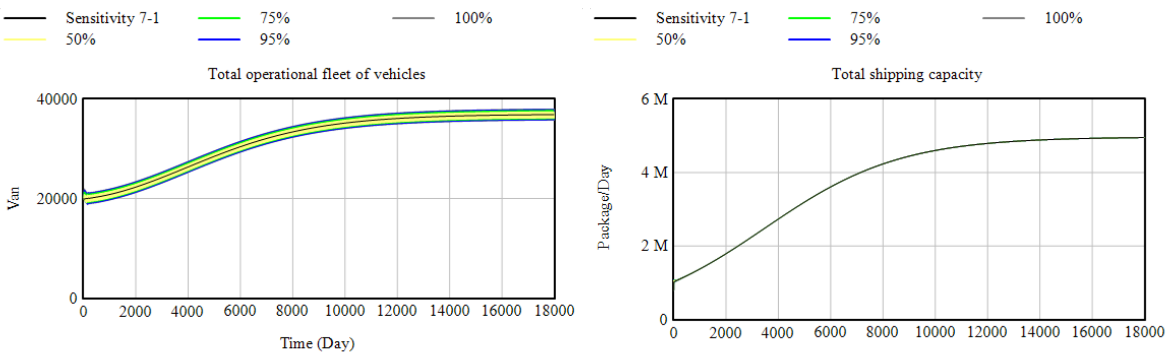


Figure E.41: Behaviour-sensitivity test of *Package delivery time* part 2

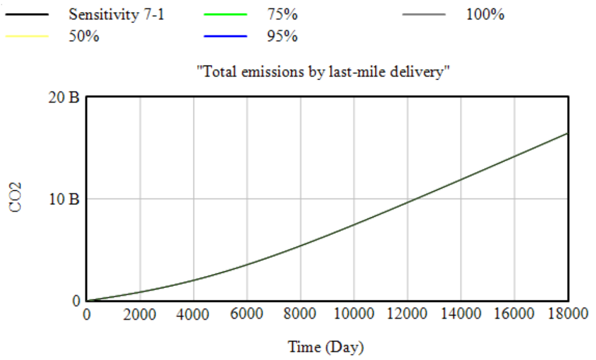


Figure E.42: Behaviour-sensitivity test of *Package delivery time* part 3