VEHICLE CLASSIFICATION IN TRAFFIC MODELS

Bachelor assignment Civil Engineering

UNIVERSITY OF TWENTE.

SWECO

Jesse Vink – s1478230

1. Summary

For traffic simulation it is necessary to know a lot of parameters. One of these is the vehicle classification. In order to be able to model a certain situation the composition of the traffic needs to be known to create a well-functioning model. There are a lot of different types and sizes of vehicles on the road, which makes it necessary for traffic simulation software to distinguish different vehicle types.

The first step for determining the correct vehicle type is by collecting the data in the first place. In the Netherlands there is a public database for traffic on most national roads, the NDW. The data that is shared by them is already classified in three or five different classifications. Whether it is three or five categories depends on the accuracy of the measurement with higher accuracy measurements being represented by the five classifications system. For urban roads the NDW does not provide that much information, but this problem is sorted by companies like Sweco performing the needed traffic measurements themselves. Sweco also uses a classification system, but that has 13 vehicle classifications. To get the optimal representation of reality by a model it is ideal that individual vehicle data is available so that the traffic simulation software can have a tailor-made vehicle classification.

Most of the vehicles are easy to determine a fitting vehicle category for in traffic simulation software. However, especially vans are a problematic vehicle category, because of the fact that they fall somewhat in between passenger cars and trucks, which are the most common vehicle categories in traffic simulation software.

To determine the influence of the vehicle classification on the capacity of a road network some simulations are run. Because urban traffic is much different from highway traffic both of these two situations are considered. The highway situation is represented by an on-ramp on a highway and the urban situation by a signalled intersection. Three of the most used traffic simulation programs used by Sweco are used to determine the effect of vehicle classification on the capacity. Fosim and Vissim are used for the highway situation and Vissim and Paramics are used for the urban situation. Not only is there looked at the maximum capacity of these situations for multiple factors of freight traffic, but also the passenger car equivalent values for the capacity is considered.

All the results show a linear correlation in the decrease of the capacity when there is an increase in the freight traffic factor. For the highways this is a decrease of around 70 vehicles per hour per percent and for the urban situation this is only around 5 vehicles per hour per percent less. The PCE-values for the highways also show a slight decrease in capacity, but only by around 20 vehicles per hour per percent less. However, the PCE-values for the capacity of the urban situation show an increase in capacity for additional freight traffic with an increase of around 3 vehicles per hour per percent freight traffic. If the PCE-values would remain the same for each freight traffic factor it does not matter in which category vans are placed. However, because this is not the case there are slight changes in capacity possible for classifying vans in a different category. These changes are up to two percent for highways and up to three percent for the urban situation when it is known that vans make up almost seven percent of all Dutch vehicles.

Table of Contents

2. Introduction

In this paragraph the reason for the research will be given, after which the research aim and research questions will be stated.

2.1. Problem description

Modelling software has the ability to distinguish vehicles into different classes. This is because cars behave different than trucks, which behave different than motorbikes. This is an essential feature for simulation software to have, because trucks are much larger and slower than cars and can therefore cause a congestion much more easily. The amount of trucks on a certain piece of road can have a big impact on the capacity of that road. It is therefore very important to be able to distinguish different types of vehicles when performing a traffic count so that it is possible to make the simulation a good representation of the actual situation.

However, a major part of the data that is used for traffic models in the Netherlands is from the NDW. This data is a very complete dataset, however it does have its limitations. The data that is collected is also shared publicly, but it does not specify what vehicle it has registered. Only the total length or the length between axles of a vehicle is given. Which of the two is given depends on what type of measurement is performed. The provided lengths are already put into classification systems and therefore it is unknown what the exact length of a vehicle is. The data given by NDW currently has two different vehicle classification systems, which depend on the accuracy of the measurements. For systems with a relatively low accuracy there are three different vehicle classifications and for relatively high accuracy systems there are five vehicle classifications. The vehicle lengths that belong to these classifications can be found in Table 1. It is also possible that a vehicle gets the classification 'not classifiable,' this happens when a vehicle is equal to or longer than 18 meters (NDW, 2013).

Table 1 - Vehicle classes by length (NDW, 2013)

Low accuracy method		High accuracy method	
Minimum vehicle length [m]	Maximum vehicle length [m]	Minimum vehicle length [m]	Maximum vehicle length [m]
-	5.60	1.85	2.40
5.60	12.20	2.40	5.60
12.20	-	5.60	11.50
		11.50	12.20
		12.20	-

From this data it is not possible to see what type of vehicle was counted. There can only be assumed as to which kind of vehicle it was. It is important to know which kind of vehicle it is to ensure that models can simulate traffic situations accurately. Simulation software is capable of distinguishing different vehicle types and their behaviour. To be able to do this accurately it is important that the input for the model specifies what type of vehicle it needs to be.

A van and a truck behave very different from each other, since a van is much more agile in traffic than a truck. Where in the range a vehicle is in its class cannot be retrieved from the data NDW delivers, which could lead to an inaccurate result of a traffic simulation due to inaccurate input. The more accurately the input for the model describes reality, the more accurate the results of the model will be. However, it is still unknown what the implications are of inputs that are not consistent with reality for traffic simulation software. The only thing that is certain for now is that the results of the models will be negatively influenced by it.

2.2. Research aim and question

For simulations to give accurate results it is important that the input for the models is as accurate as possible. Every vehicle class behaves differently in traffic, so it is imperative for the input to be as precise as possible regarding the vehicle classification. The more exact a dataset for the input of a simulation is, the more reliable the results of a simulation are.

Unfortunately, complete perfection for the input and behaviour of vehicles is impossible to achieve. It is therefore important to know what the effects are of small differences in the definitions of vehicle classes. When there is known what the effects are, and especially how much they influence the results of a simulation, it is possible to say something about the accuracy of a simulation. Therefore, the following research question has been formulated:

"What is the influence of vehicle classification on the capacity of an analysed road network in a traffic model simulation?"

It is especially interesting to look at vehicles that fall in between categories. Vehicles exist in all shapes and sizes, but for simulation only a few categories exist. For passenger cars it is easy to determine the correct category, because there generally is only one category for passenger cars. However, for vans in particular it is difficult to classify them in the correct classification, since they could be considered as a passenger car or as a larger vehicle like a truck. Vans make up a considerable amount of vehicles in the Netherlands, because they amount for approximately seven percent of all registered vehicles in the Netherlands (CBS, 2020).

2.3. Research scope

Sweco is a company that does a lot of traffic modelling. It uses a variety of traffic simulation software with each its own input parameters and model set-up. All programs use the data from NDW as its input for the simulations, but also data gathered by companies like Sweco themselves. It is therefore interesting for Sweco to see what the effects are of the classification already done by NDW. Additionally, it is interesting to see whether the impact on the simulations is the same in different types of simulation software for similar situations.

Highway traffic is different from urban traffic, among other things because of the difference in speed and the number of junctions. Therefore, there might be differences in how the capacity is impacted by the different classification methods. Because of this both an urban and a highway situation are modelled to be able to distinguish these two situations.

2.4. Research method

To get an answer on the research question a certain method will be followed, which will now be elaborated on further. First, it is important to know how the data is gathered and how this data is handled and stored until it is used for traffic modelling. This is done by performing a literature study into the different traffic measuring methods, but also by looking into the databases that are used for traffic modelling. Then there is looked at the different traffic modelling programs how they handle different vehicle classes and especially into how these different classes are defined in each program. Next, there are some basic situations that have been simulated to see what the differences are when vehicle classification is done in a different way. Two situations are used for this, one with a highway on-ramp and one for a signalled intersection. In this way two completely different situations are evaluated. Finally, there is looked at how much the different programs react to the same situation. For the highway situation Fosim and Vissim are used, whereas for the urban situation Vissim and Paramics are used.

3. Vehicle measurement

In order to be able to say something about the influence of vehicle classification in traffic modelling it is also important to know how the data for the input is gathered. If the data retrieved by a vehicle measurement is not accurate then the traffic model representing it will not be accurate either. It is therefore very important to know how data is gathered and how exact this data is. Furthermore, as can be seen in Table 1 the main source of highway data already has a classification. It is important to know why this classification has been chosen and whether this is a universal classification, because if other sources use a different classification or even none at all that would give different outcomes of traffic simulations.

3.1. Vehicle measurement techniques

There are a lot of different ways to determine the number of vehicles on a road segment. However, for this research it is especially important that the length of a vehicle can be registered and not just the number of vehicles that have passed a measuring site. If a measuring method can determine the length of a vehicle this means that it can register the beginning and the end of a vehicle, which means counting individual vehicles is possible as well. Determining the length of a vehicle is very important to be able to make a distinction between vehicle classes. Methods that just register a vehicle and not its length are not suitable for this research and will thus not be considered in this report.

There are two main ways the length of a vehicle can be determined. The first is to measure the actual length of a vehicle and the second is by counting the axles and determining the distances between them. The length can be derived from the speed a vehicle travels at and the time it takes between the different axles. Which of the two definitions for length of a vehicle is given depends on the measuring method that is used.

Furthermore, there is a difference between intrusive and non-intrusive technologies, where intrusive means that the measuring installation is somehow connected to the road itself. Non-intrusive methods can be installed on the side of the road or overhead. This is important because for an intrusive method the road often needs to be adjusted in order for the measuring system to be installed. This can be done by cutting or boring in the road surface for example. Making changes to the road surface could lead to a lower lifetime of that road due to higher degradation of the road surface.

Moreover, there is a difference between permanent and temporary traffic measurements. Permanent or continuous counts are performed year-round. Generally, these counts provide information about seasonal changes in traffic. Temporary traffic measurements are of short duration, meaning that they often only measure traffic for one or two weeks at a time. These short duration measurements are practically always performed with portable measurement systems so that they can be re-used later at other places where information is needed (FHWA, 2016).

Some measuring methods are also able to determine the weight of a vehicle while it is driving. These systems are called Weigh-in-Motion (WiM) and often consist of multiple methods combined to get all the data. In the Netherlands there are 10 WiM stations and consist of a vehicle detection system, an axle load sensor and an identification system. Where these measuring sites are can be seen in Figure 1. The detection systems are inductive loops which measure the length and speed of a vehicle. Then the vehicle passes the axle load sensor which measure the distances between and the loads on individual axles. Finally, the identification system is a camera that registers a vehicles license plate from both the front and the back. Both sides are important, because a tractor has a different number plate than the trailer it carries and both are necessary to determine the total length and weight of the combination (E. Kuiper, 2013).

Figure 1 - Weight in Motion network Rijkswaterstaat (Rijkswaterstaat, Weight in Motion Netwerk Rijkswaterstaat, 2020)

3.2. Most used Dutch methods

As mentioned before there are a lot of ways to measure traffic volumes and length of vehicles. For length there are two major categories in which it is defined, actual length and axle distance(s). In the table below the most used methods in the Netherlands are explained and sorted on which type of length results they deliver.

Table 2 – Most important traffic measurement methods sorted on type of length measurement

Type of classification	**Method**	**Description**
Length-based	Video detection system	Cameras aimed on a stretch of road register passing cars. More advanced software is also able to determine vehicle length. Number plates recognition can be used to determine the exact length of a vehicle. However, not every vehicle length is in the RDW database and due to privacy regulations registered license plates cannot be stored in a database, only its length.
	Inductive loops	An inductive loop is generally inside the road surface and it has a certain frequency. This frequency changes when a metal object is on top of it and this is registered as a vehicle. To measure the length of a vehicle there need to be two loops close together to be able to determine the length of a vehicle.
Axle-based	Double road tubes	Tubes are installed on a road and every time a vehicle crosses over it the air pressure inside the tubes changes, which is registered. Using the known distance (generally one meter) and the time measured between the crossing of the first and second tube delivers the speed of a vehicle. When the speed of an axle is known it is also possible to determine whether the next axle also belongs to that vehicle. A vehicle always has at least two axles, so when the speed of two following axles is identical this generally means that it is the same vehicle. When vehicles are driving in line their speed will also be practically identical, so for this the distance between the axles is taken, because the distance between the axles of a car is smaller than the distance between the last axle of the first vehicle and the first axle of the following vehicle. Finally, the tubes need to be installed perpendicular to the driving direction to prevent one axle to deliver two different passing times.
	Piezo-electric sensors	A piezo-electric sensor is based on the fact that some materials generate a small amount of electricity when a load is applied to them. If a vehicle drives over a piezo-electric sensor this sensor will register the load of the wheels and thus the axles. The calculation of the length is the same as for the road tubes.

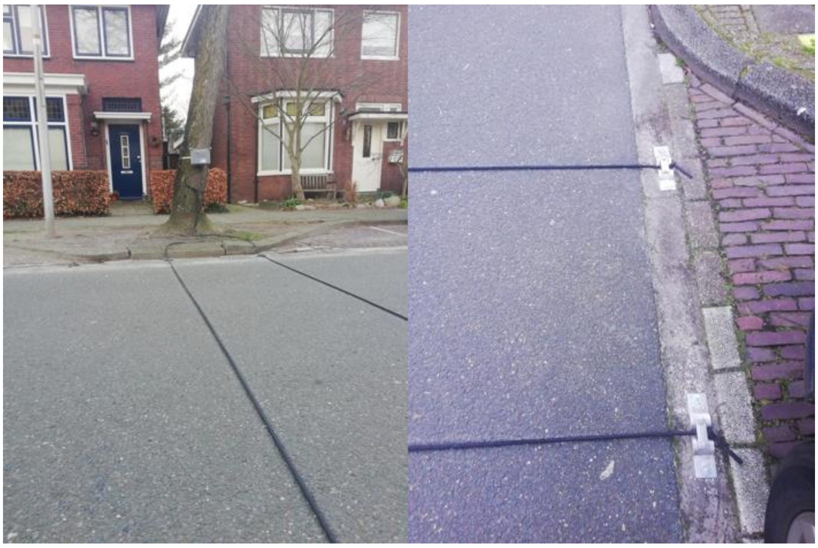


Figure 2 - Left: road tubes installed on a road. Right: end of the tubes drilled into (the edge of) the road surface

3.3. Vehicle measurement locations

In the Netherlands there is excellent coverage of traffic counts on the national highway network. The red lines in Figure 1 show the trajectories of all Dutch national highways. According to the NDW there even is coverage of 100% of the Dutch national highways (NDW, Actuele verkeersgegevens, 2020). The standard for traffic measurements on highways are induction loops. These loops are milled into the road surface to keep the road surface smooth. Road tubes would not be as suitable, because they are likely to break due to the high speeds that they are exposed to on a highway. Also, road tubes could experience occlusion, which means that if two vehicles that drive next to each other they will be counted as one vehicle due to the fact that the wheels pass at the same time. Furthermore, there will be problems with vehicle class determination if vehicles are driving next to each other because it is impossible for the tubes to determine on which lane the detected axle is. Induction loops do not have problems when vehicles drive next to each other. Only when a vehicle changes lane a problem occurs, because an induction loop is generally on a specific lane and while changing lanes a vehicles is temporarily at two lanes at the same time.

It is impossible to measure traffic on every urban road. Besides, this is not really interesting anyway, because on most streets the traffic intensity is much lower than the capacity. If the traffic on an urban road needs to be measured it is quite easy to install road tubes. Generally, counts are performed for a duration of a week so that there is a good view of the traffic intensity throughout the week. The installed road tubes can then be removed and used somewhere else. If there already is a measuring system present in the road this can of course be used, but often this is not the case.

The major urban roads are the most interesting to measure the traffic on, since here the road capacity might be a problem for a good flow of traffic. On these major roads there are a lot of signalised intersections to regulate traffic. In the Netherlands there are around 5600 signalised intersections (Willekens, 2016). A lot of these intersections have the ability to determine the number of vehicles waiting per direction and adjusting green times accordingly to improve traffic flow. This data can also be used for traffic counts, because the standard for determining the number of vehicles is by use of induction loops. As mentioned before, these loops are capable of determining the length of a vehicle and thus in which vehicle class it belongs. However, when the maximum capacity of a signalised junction has been reached the data is not very reliable anymore because the peak might continue on for much longer than it would be when the maximum capacity is not yet reached.

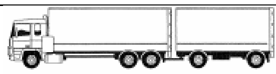
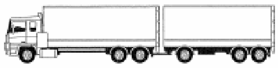
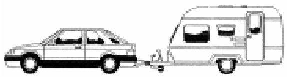
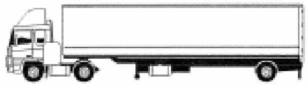
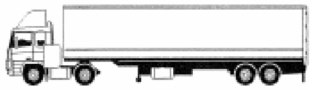
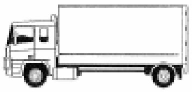
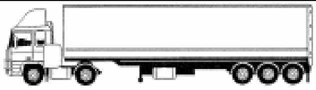
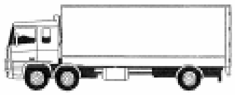
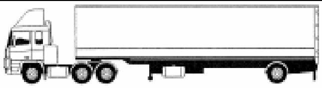
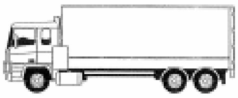
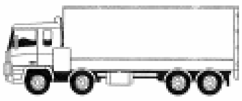
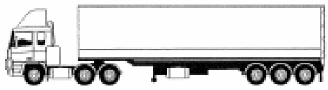
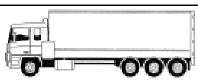
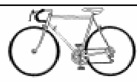
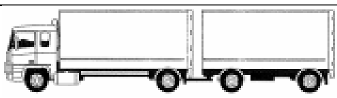
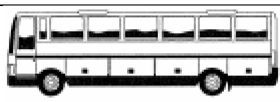
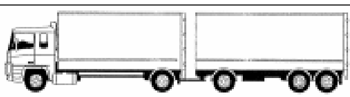
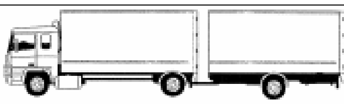
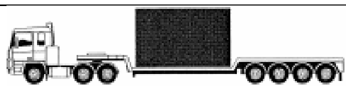
3.4. Vehicle classification systems

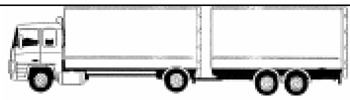
Vehicle classification can have multiple purposes. For example, it can be used for the determination of the greenhouse gas emission by the traffic or for the modelling of the traffic flow of a certain section of the road network. For this report the latter option will be the goal of the vehicle classification, but the other option also has an influence on some vehicle classification systems. The data from NDW is only classified into five different classes, but other classifications divide vehicles up into up to 13 different categories. Most of these extra classes are for different kinds of trucks, but this differs per classification system.

The idea behind dividing traffic up into different categories is because traffic is not homogenous. Every vehicle has a different length, a different weight and every driver behaves differently. To be able to simulate traffic it would be ideal to have the exact parameters for every individual vehicle. However, this is not feasible, because all data would need to be gathered and every vehicle react different to similar situations. It is therefore very interesting to create only a few vehicle classes, which allow for a simplification of reality. The question then is how to divide the different vehicles into which and how many classes. There exist multiple different classification systems, some of them will be elaborated on below. There are three major categories in every classification system: passenger cars, trucks and tractors with trailers. In some systems these categories will be further subdivided, but in all systems these categories can be distinguished. This is because most vehicles will fit into one of these categories and the behaviour of these three categories is very different from each other.

As mentioned before, all data for traffic simulation comes from traffic measurement. NDW gathers a lot of data, but some companies also perform these measurements themselves. These measurements are often of short duration, as they will be used for specific projects for companies themselves. Sweco too performs traffic measurements of a short duration. They currently use the double road tubes as a method to measure the traffic. These tubes are relocatable, so when one location is measured, they can be used again on another spot. Their installations give results in 13 different classifications, from which one is for cars, one for bicycles, one for buses and the other 10 are for trucks of all different sorts. An overview of all the different classifications can be found in Table 3.

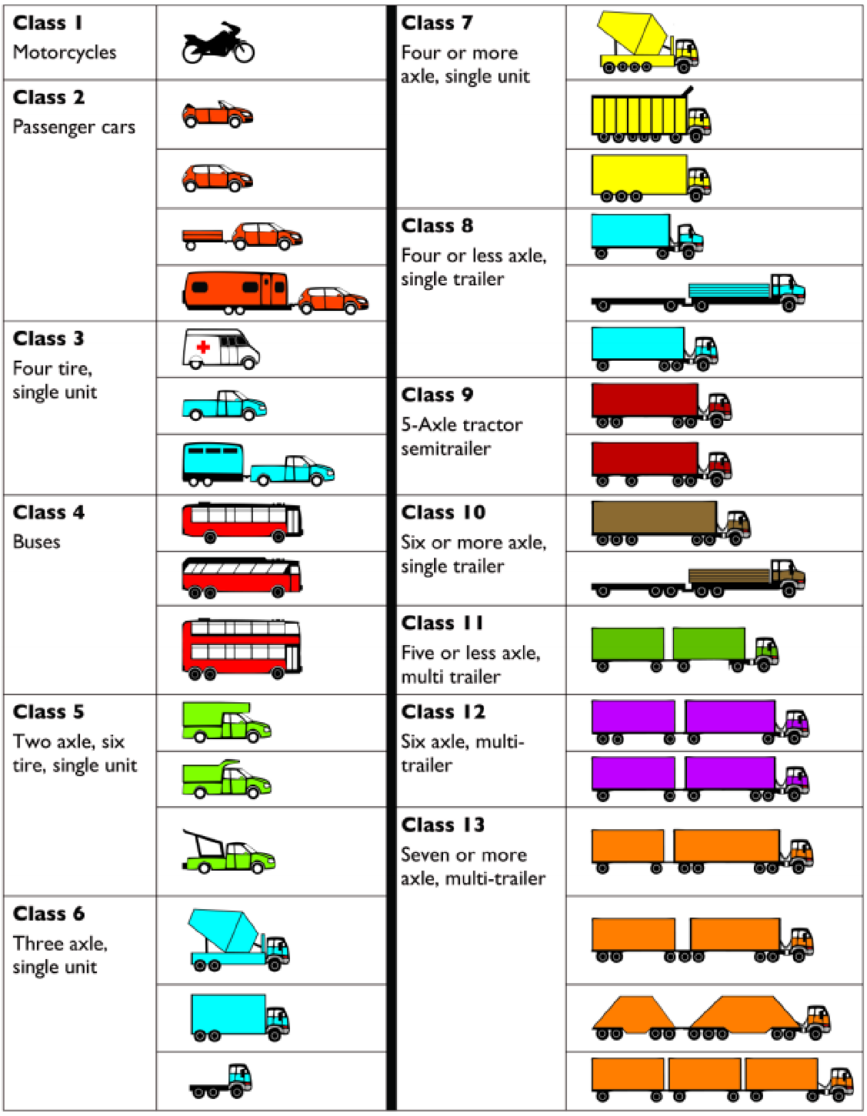
Table 3 - Overview of the classification system used by Sweco

1	Passenger cars		6	5-axle trucks	
	Vans			6-axle trucks	
	Passenger cars + single axle trailer		7	2-axle tractor + single axle trailer	
	Passenger cars + 2-axle trailer		8	2-axle tractor + 2-axle trailer	
2	2-axle trucks		9	2-axle tractor + 3-axle trailer	
3	3-axle trucks		10	3-axle tractor + single axle trailer	
	3-axle trucks			3-axle tractor + 2-axle trailer	
4	4-axle trucks			3-axle tractor + 3-axle trailer	
	4-axle trucks		11	Bicycles	
5	2-axle truck + 2-axle trailer		12	2-axle bus	
	2-axle truck + 3-axle trailer			3-axle bus	
	2-axle truck + single axle trailer		13	Vehicles with 7 axles or more	

	2-axle truck + 2-axle trailer			All non-mentioned vehicles	

The Federal Highway Administration (FHWA) in the United States also uses 13 different vehicle classifications. However, this classification system is different from the one Sweco uses. They do not include bicycles, however they have included motorcycles. There are two different classifications for cars, where one classification concerns slightly bigger cars than the other (FHWA, 2016). An overview of the FHWA vehicle classification can be found in Table 4. However, although the FHWA does collect the data in these 13 categories most states use a system with only three or four categories. The four categories consist of cars, small trucks, large trucks and multi-trailer trucks. The three category system is the same as the four category classification except for the fact that large trucks and multi-trailer trucks are combined into one category.

Table 4 - Overview of the classification system used by the FHWA (FHWA, 2016)



Class 1 Motorcycles	**Class 7** Four or more axle, single unit
Class 2 Passenger cars	**Class 8** Four or less axle, single trailer
Class 3 Four tire, single unit	**Class 9** 5-Axle tractor semitrailer
Class 4 Buses	**Class 10** Six or more axle, single trailer
	Class 11 Five or less axle, multi trailer
Class 5 Two axle, six tire, single unit	**Class 12** Six axle, multi-trailer
	Class 13 Seven or more axle, multi-trailer
Class 6 Three axle, single unit	

For both classification systems it is possible to convert them so that they suit the NDW classifications. This means putting some classifications together to form the NDW classification. An overview of to perform this conversion can be found in Table 5.

Table 5 - Conversion from Sweco/FHWA to NDW classification

	Original classification	NDW 1	NDW 2	NDW 3	NDW 4	NDW 5
Three classifications	**Sweco**	1	2-4, 12	5-10, 13		
	FHWA	1-3	4-7	8-13		
Five classifications	**Sweco**	-	1	2-4	12	5-10, 13
	FHWA	1	2, 3	5-7	4	8-13

As can be seen in the classifications by Sweco and FHWA there are a lot of classes for trucks, while cars only have one or two classes. This is because trucks vary a lot more in their behaviour on the road since there a lot of different combinations possible, which all mean a different reaction to certain situations. Trucks also have a big influence on the capacity of a road, because they take up a lot of space and can change speed or direction much slower than cars can. Also, the weight of a truck matters: a fully loaded truck is much heavier than an empty one. It is therefore very interesting to look at data from WiM how the division of mass in trucks looks like. In Figure 3 an example of results coming from a WiM measurement can be seen. The colours show the number of measurements for a specific combination. For this figure only vehicles that are longer than seven meters are considered (E. Kuiper, 2013). On the x-axis is the distance from the first to the second axle and on the y-axis is the axle load on the first axle.

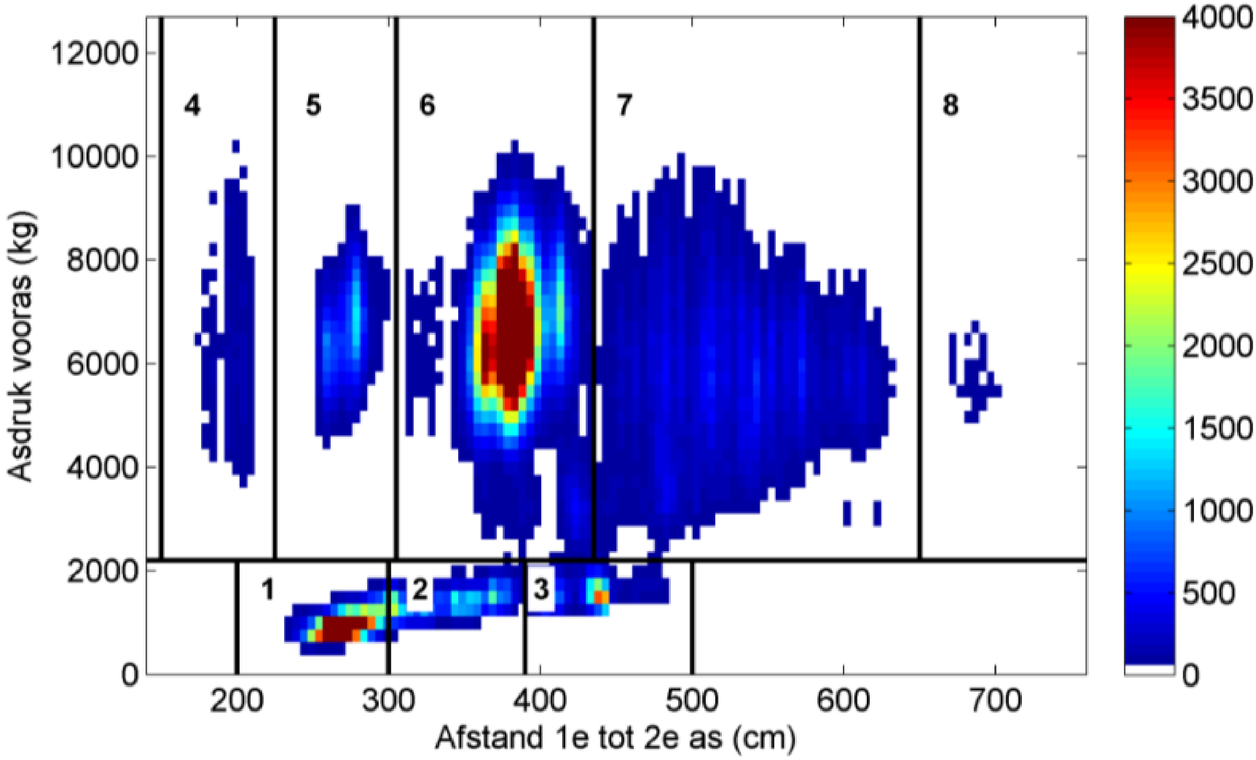


Figure 3 - Axle load on the front axle for the distance between the 1st and 2nd axle (E. Kuiper, 2013)

From the graph it is possible to distinguish 8 different types of vehicles, which is also indicated in the figure. The explanation of the eight different vehicle types can be found in Table 6. Vehicle types 1 to 3 are considered as light vehicles and the other five are considered heavy traffic.

Table 6 - Vehicle types following from Figure 3

Number in Figure 3	Vehicle type
1	Passenger cars
2	Vans
3	Small trucks
4	Dump trucks
5	Tractor 3-axles
6	Tractor 2-axles
7	Trucks
8	Buses

As mentioned before, the vehicles that have been registered for the WiM measurement for Figure 3 are at least 7 meters in length. Regular cars are therefore not taken into account for the data, however there are a few passenger cars visible in the figure because some cars have a trailer and therefor reach the 7 meter threshold. All vehicles that are smaller than this seven meters can be seen as passenger cars or maybe as a van, but as the Sweco system shows vans are registered in the same vehicle class as passenger cars. Also, motorcycles might have been registered but this data was not saved due to the seven meter limit. Cyclists will not have been registered since the ten measuring sites were all on highways where cyclists cannot come.

Looking back there can be concluded that the technique is capable of measuring individual vehicle lengths. Generally, all these individual vehicle lengths are immediately put into a classification system before they are saved or even made public. The way this is done makes it impossible to get the data for individual vehicles if this would be required. If the classification used for the measurement is the same as for a traffic modelling program this would deliver the correct results. However, it is seldom the case that modelling software uses the same categories as the classifications resulting from measurements. This means that some vehicles will be placed in a different category than it ideally should be for that program. If individual data is available the classification can be done correctly for each program. Although different programs generally use similar categories, they are not all defined identically, as is elaborated on further in the next chapter.

4. Vehicle classes in simulation software

In this paragraph the different vehicle classifications of three traffic simulation programs will be compared to the vehicle classification by the NDW. The reason that these three simulation programs have been chosen is because they are among the most used programs that Sweco uses. Fosim is able to model only highway situations and will therefore only be used to model that situation. Paramics is able to model highway situations, but for times sake there has been chosen to only simulate the urban situation in Paramics. Vissim is the only program in which both situations are modelled.

Although the databases from NDW only have data available for national roads these databases will be used as the reference classification system with which the different simulation programs will be compared. National roads are among the busiest roads in the Netherlands and are thus a good representation of vehicle composition in traffic because of the amount of vehicles. Because of the fact that there are two different classification systems used by NDW one has to be chosen. There will be assumed that the accuracy of the input is high, which means that the system with five categories will be used for the comparison. The overview of these classes can be found in Table 7.

Table 7 - NDW vehicle classification with five classes

Vehicle class	Minimum vehicle length [m]	Maximum vehicle length [m]
1 – motorbike, scooter	1.85	2.40
2 – passenger car, van	2.40	5.60
3 – truck	5.60	11.50
4 – bus	11.50	12.20
5 – tractor + trailer	12.20	-

4.1. Fosim

At first instance it looks like Fosim has five different vehicle classifications. However, after looking a little bit closer there can be concluded that there are only three types of vehicle really. This is because there is made use of vehicle-driver combinations. The first three vehicle-driver combinations are all for passenger cars with minor differences between the three categories. The other two categories are for trucks, where category four can be considered as NDW category 3 - truck and category five as NDW category 5 - tractor plus trailer. This also means that the remaining NDW categories 1 and 4 are not represented in Fosim.

The first three categories are all for passenger cars, however, they are not the same. There has been chosen to create these three categories, because by dividing the category of passenger cars up it is possible to have the same vehicle class react differently to similar situations. Not every road user has the same driving style and Fosim tries to apply this in its simulation by having the three different types of drivers and thus three vehicle classes for just passenger cars.

Furthermore, Fosim has the option to adjust each parameter for a vehicle class. There are a minimum and a maximum value for each parameter and it is very easy to adjust a parameter by moving a pointer along a scale. An example of how this looks like can be seen in Figure 4. Fosim has been calibrated and validated for the current parameter values for the five categories, so there is advised that there should not be fiddled with the current values (Dijker & Knoppers, 2006).

Parameter	Minimum	Maximum	Waarde
max. sprong acc.	0.1 m/s³	10.0 m/s³	1.0 m/s³
z2	0.10 s	10.00 s	0.56 s
max acc.	0.1 m/s²	8.0 m/s²	4.0 m/s²
max volgdec.	-2.0 m/s²	0.0 m/s²	-0.5 m/s²
strookwisseldec.	-8.0 m/s²	0.0 m/s²	-3.0 m/s²
max dec.	-8.0 m/s²	-3.0 m/s²	-7.0 m/s²
wenssnelheid (120)	75.0 km/h	200.0 km/h	125.0 km/h
lengte	3.0 m	26.0 m	4.5 m

Figure 4 - A part of the adjustable parameter screen of Fosim

4.2. Vissim

Vissim has four different predefined vehicle categories: car, HGV (Heavy Goods Vehicle), bus and tram. There are categories for men and women as well, but these are not relevant for the traffic simulations in this report since they are pedestrian categories. The tram category will not be considered for this report either, because in this report there is especially looked at the effects of vehicles being defined in one class or another. A tram does not have a problem in which category it would fall, since it is a completely different vehicle than the rest of the traffic. It will therefore not deliver useful information for this purpose. The car category in vissim can be compared to the car category from NDW. The vissim bus category can also be taken as the NDW bus category. The length of the HGV in vissim is 10,2 meter, so this would mean that it can be compared to category 3 – trucks from NDW. This also means that NDW categories 1 and 5 are not represented in vissim.

4.3. Paramics

In paramics there are eight vehicle categories, which all have their own predefined properties. The vehicle classes are: cars, light goods vehicles, medium goods vehicles, heavy goods vehicles, coach, single decker bus, double decker bus and bicycles. This means that there are basically three categories for both trucks and buses. Cars can simply be taken as the passenger car and van category of NDW. NDW category 1 – motorbike, scooter does not have a representative category in Paramics.

The light goods vehicle class has a length of 6 meters with a weight of 2,5 ton. This is reasonably small and thus there can be assumed that this is the category for a van, which means that it would be considered as category 2 – passenger car, van. The medium goods vehicles have a length of 8 meters and can therefore be considered as category 3 – truck in the NDW classification. The heavy goods vehicles are longer and much heavier than this and can be considered as the highest category: 5 – tractor plus trailer.

It seems weird that there are three categories for buses alone, but already makes more sense when considering that paramics is a British traffic simulation program. Unlike the Netherlands there are multiple cities in the UK that have double decker buses, which explains the existence of this category in paramics. This category will not be used in this report, since in the Netherlands instead of double decker buses articulated buses are used. The difference between the other two bus categories, the coach and the single decker bus, is the fact that the single decker bus is generally a bus for public transport and the coach is a bus that can be used more freely and is also more suited for highways. The dimensions of the buses are practically the same, but the coach is faster and can change speed quicker, meaning both acceleration and deceleration. Both single decker buses and coaches can be considered in the category 4 - bus by NDW.

Table 8 - Conversion table for vehicle classes for NDW and the simulation software

NDW vehicle class	Fosim vehicle class	Vissim vehicle class	Paramics vehicle class
1 – motorbike, scooter	-	-	-

2 – passenger car, van	1, 2, 3	Car	Car, Light goods vehicle
3 – truck	4	HGV	Medium goods vehicle
4 – bus	-	Bus	Double decker bus, single decker bus, coach
5 – tractor + trailer	5	-	Heavy goods vehicle

4.4. Important parameters comparison

For this paragraph it is especially important to know the parameters of the vehicle that have an influence on the capacity of a road segment. The length of a vehicle is very important, because it takes more time for a long vehicle to pass a point than it does for a short vehicle. The speed at which a vehicle travels also has an influence, since a vehicle will leave a spot earlier and thus make room for a next vehicle. Speed is more important on a highway than in a city, because all vehicles are able to drive the speed limit within the city limits (50 km/h), whereas not all vehicles will reach the maximum speed on a highway (100 km/h). The speed limit for a highway is chosen to be 100 km/h, because this is the new speed limit in the peak hours and will therefore be the most interesting to look at.

The acceleration of a vehicle is important as well, because the sooner a vehicle can leave a place, the sooner there is space for the next vehicle. There is assumed that all virtual drivers have the same reaction time, which is also what is the case in all three programs. The acceleration is more interesting for the signalised intersection, because when a traffic light turns from red to green vehicles will have to accelerate to get moving. On a highway vehicles already have speed in free flow situation and acceleration only is important really when a traffic jam has formed and vehicles need to get moving again. Furthermore, the deceleration is important, because for the signalized intersection vehicles need to brake when the traffic light is red and they approach. On a highway vehicles might need to brake when there is a traffic jam coming up or there is a slower driving vehicle in front of them. The ability to change speed is thus important in general.

Since vehicle category 1 is not represented in any of the three models it will be left out in the overview of all the properties. The overview of all the different vehicle classifications can be found in Table 9. Empty cells mean that there either is no representative vehicle class in that simulation program or that the information is not relevant for the research. There are three categories that have multiple values per cell. The one for Fosim is because there are three vehicle-driver combinations for passenger cars, so all three are mentioned. The numbering of these categories is the same as it is in Fosim. Category 2 for Paramics also consists of two values, these are the values for cars (1) and the values for light goods vehicles or vans (2). Finally, there are multiple values for category 4 in Paramics. The first value is for coaches while the second value is for single decker buses.

The speed limit on Dutch highways has changed from 120 km/h to 100 km/h in march 2020 (Rijkswaterstaat, De maximumsnelheid in Nederland, 2020). Since this is a very recent change there has not been time yet to adjust Fosim to this new speed limit. It is still calibrated for highways with a speed limit of 120 km/h, so for passenger cars the desired speed is not calibrated properly yet. However, there is a graph that shows the desired speed for different speed limits for all vehicle-driver combinations (Dijker & Knoppers, 2006). The desired speeds for category 4 and 5 remain the same, since their maximum allowed speed is lower than 100 km/h and will thus not be affected by the new speed limit.

The desired speed for Vissim is not a single value, but a distribution. The ranges are given for just the speeds and are independent of the vehicle class. The ranges that are given in Table 9 contain about 90% of the speeds that vehicles will drive. Not the entire range is given because this would give a distorted view, since only a few percent is are near the edges of the range. By narrowing it down like this it is easier to compare the values between the different programs.

The desired speed in Paramics is not a fixed value either. The distribution of desired speeds is unknown, however, it is known that the desired speed depends on the aggression level of a vehicle (Sykes, 2010). Vehicles will drive up to 10% faster than the speed limit (Pitney Bowes, 2020) depending on the level of aggression. There is assumed that vehicles will also drive up to 10% slower than the speed limit when their aggression level is on the low end of the spectrum.

The values for acceleration and deceleration in Fosim are maximum values. Although there is only one type of acceleration there are three types of deceleration in Fosim: regular deceleration, following deceleration and lane change deceleration. All of these values are maximum values. The maximum deceleration is much higher than the values for following and lane changes, so there has been chosen to show the values for the regular deceleration. The maximum acceleration and deceleration in Vissim are functions. The slower a vehicle drives, the higher the change of speed can be. The values given in Table 9 for acceleration and deceleration are the values for maximum acceleration and deceleration at 50 km/h.

Table 9 - Important parameters per vehicle class for the three simulation programs

	NDW Vehicle category	Fosim	Vissim	Paramics
Length [m]	**2**	(1) 4,5 (2) 4,0 (3) 4,0	3,75 - 4,76	(1) 4,0 (2) 6,0
	3	8,0	10,22	8,0
	4		12,4	(1) 10,0 (2) 10,0
	5	14,0		11,0
Desired speed highway[km/h]	**2**	(1) 113 (2) 105 (3) 100	95 – 120	
	3	95	80 – 100	
	4		80 – 100	
	5	85		
Desired speed urban [km/h]	**2**		48 – 58	(1) 45 – 55 (2) 45 – 55
	3		48 – 58	45 – 55
	4		48 – 58	(1) 45 – 55 (2) 45 – 55
	5			45 – 55
Acceleration [m/s^2]	**2**	(1) 4,0 (2) 2,4 (3) 2,4	1,96	(1) 2,50 (2) 1,80
	3	1,0	0,95	1,10
	4		1,00	(1) 1,20 (2) 0,90
	5	0,4		1,40
	2	(1) -7,0 (2) -7,0	-7,00	(1) -4,50 (2) -3,90

Deceleration [m/s²]		(3) -7,0		
	3	-6,0	-5,50	-3,20
	4		-7,00	(1) -3,70 (2) -3,20
	5	-6,0		-3,70

When looking at the table above some expectations can be made. Both the two simulation situations, highway and urban, will be handled below on what the expected outcomes will be of the simulations.

For the highway it is interesting to see what the effect is of the fact that there only is one vehicle class for freight traffic in Vissim, whereas Fosim has two categories for that. Fosim has vehicles of NDW category 5, so when looking at that it would seem logical that the capacity of Fosim would be a little lower than the value gotten in Vissim. The desired speeds are very comparable for the different programs, the only difference is that Vissim has a distribution for this and Fosim has a value that is around the median of that of Vissim. Because this is around the average value of Vissim this is not likely to create much difference. What might make more of a difference is the acceleration, which is much higher in Fosim than it is in Vissim. Although, this is only for passenger cars it might make a difference because there are much more passenger cars than there are freight vehicles.

For the urban situation there also is the difference in amounts of different vehicle classes that can be simulated. Vissim still does not have NDW category 5 vehicles where Paramics does have this vehicle class. Since the speed limit can be reached by every vehicle, this will hardly make a difference. Moreover, both programs have a distribution for the desired speed. The deceleration of vehicles in Paramics is much lower than what it is in Vissim, so when vehicles have to stop they take longer to do it in Paramics, which will have a negative influence on the capacity.

When looking at the potentially most problematic type of vehicle, which is the van, there can be noticed that this vehicle class only exists in Paramics. However, because this class is not in most databases as a separate vehicle class, the functioning of this is questionable. There has to be estimated how many vehicles are vans and how many vehicles are passenger cars or larger types of freight vehicles. For Fosim and Vissim it is even more difficult, because those programs do not have a vehicle category for vans, which means that they will have to be put together with other categories that represent them other than a dedicated category would.

5. Simulations

First of all, the traffic situations need to be created in the different software. There is no need to create very ingenious situations as basic situations will suffice for this research. There is chosen for basic situations that form some kind of bottleneck for both a highway situation and an urban situation. The speeds and amount of intersections differ greatly and the results are therefore likely to be far apart. The situations will be at a bottleneck, because that is where problems in capacity occur and it is important to know the capacity of a road at those places. For the highway situation this is an on-ramp on a highway, which means that the amount of lanes goes from three back to two. The urban situation will consist of a signaled intersection with a traffic light. Further details about these situations can be found in the following paragraphs. Finally, to be able to compare different programs the two situations need to be as identical as possible across the different programs.

5.1. Highway situation

The highway situation will consist of a two-lane highway with an on-ramp and will be modelled in both Fosim and Vissim. The highway will have 2000 meters before it reaches the on-ramp so that vehicles are able to settle in and create a representative highway traffic flow. Vehicles coming from the on-ramp have a run-up of 500 meters, also to give them the time to settle in. The insertion lane itself will be 200 meters long, which is the normal length for an insertion lane in the Netherlands (ANWB, 2020). After the vehicles from the on-ramp have joined the rest of the highway traffic and the insertion lane has ended there is another stretch of 1500 meters for vehicles to cover. The speed limit on the highway itself will be 100 km/h, since this is the speed limit on highways in the Netherlands. The speed on the on-ramp will be lower due to the fact that vehicles need to get up to the desired highway speed. On-ramps in the Netherlands are designed in such a way that the speed level is one level lower than the highway itself, which means that the speed on the on-ramp will be 70 km/h (Rijkswaterstaat, Richtlijn Ontwerp Autosnelwegen 2017, 2017). It is assumed that freight traffic is able to get up to this 70 km/h when entering the merging lane, this could mean that the 100 km/h has not yet been reached when it is already on the highway itself.

The fraction of freight traffic is important for the capacity of a highway. For these simulations the starting ratio of freight traffic is 10%. Because the fraction freight traffic on highways generally is around 10%, there is chosen to run simulations with a freight traffic percentage ranging from 5 to 15%. In Fosim there are two different categories that represent freight traffic, whereas in Vissim there only is one category that does. However, the average of the two Fosim categories is not far off the values of the one category that exists in Vissim. Therefore, there can be assumed that the values retrieved from the simulations can be compared to each other as long as the total fraction of freight traffic remains the same.

The category that represents buses cannot be simulated in Fosim, however it is possible to simulate buses in Vissim. Buses only form a very small fraction when looking at the total amount of traffic, partly because there hardly are any public transport lines which routes takes them over a highway. The few buses that do drive on a highway could also be considered as (medium) heavy traffic, which is also done in the three category classification system from NDW. Therefore, for the highway situation there has been chosen not to include buses as a separate category, but to consider them as freight traffic instead. This also makes it possible to better compare the data from Fosim and Vissim later on, since the used categories will be the same.

The vehicle input also needs to be determined in order to determine the capacity of the highway. Guidelines suggest that the capacity of a highway is around 2000 vehicles per hour per lane. The more lanes there are the lower the capacity per lane becomes, because then there are more possible lane changes, which decreases the capacity of a road. For a highway situation with two lanes or for a situation with two lanes and an insertion lane the capacity would be 4200 vehicles per hour (Goemans, Daamen, & Heikoop, 2011). This capacity is for a traffic situation in which 15% of the traffic is freight traffic. Because this research aims to determine the influence of the vehicle classification on the capacity the fraction of freight traffic will be changed. This should have an influence on the capacity and a single intensity might therefore not be the best option for all scenarios. The solution for this is to create a progressive intensity starting with 2500 vehicles per hour on the highway and 250 vehicles per hour coming from the on-ramp. This will gradually increase over the time of two hours (7200 seconds) to 5000 and 500 respectively. The fraction of traffic coming from the on-ramp will remain at 10% of the value for the highway itself. The starting value of 2500 has been chosen because at that intensity it is certain that the highway will have the capacity and thus that the simulation will start in a free flow state, even when the fraction of freight traffic is made higher.

The capacities that will be determined by the simulations will be given in vehicles per hour. This only gives enough information about the relative capacity when also the freight traffic factor is known. The difference in capacity can change a lot for varying freight traffic factors. That is why also the capacity for a passenger car equivalent (PCE) will be given. For a highway the passenger car equivalent of a truck is 2,3 passenger cars (Rijkswaterstaat, PAE-waarde van vrachtverkeer in relatie tot wegcapaciteit, 2010). On highways there are hardly any differences between the PCE for a truck or a tractor with trailer.

5.1.1. Fosim

What the highway model looks like in Fosim can be seen in Figure 5. In this model there have been added a few detectors as well. These are for measuring the traffic like actual detectors would in a real road. They have been set-up so that there is a detector every 250 meters. The capacity will be measured at the last detector, because there the vehicles from the on-ramp have been able to properly merge in with the traffic that was already on the highway.

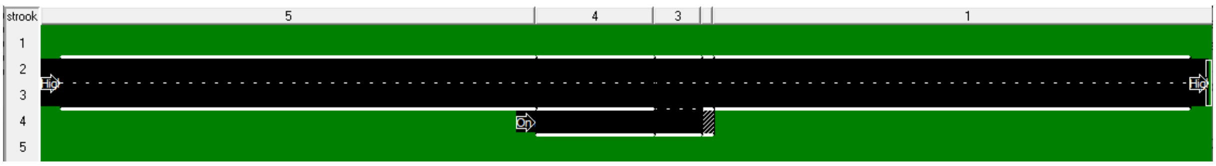


Figure 5 - Highway on-ramp modelled in Fosim

As mentioned, the initial freight traffic fraction is 10%. In Fosim there are two ways to set up the fraction of freight traffic: either by directly determining the freight traffic percentage or by determining the fraction per vehicle category. However, when adjusting the fractions in one of the options the other option will automatically adjust accordingly. Furthermore, Fosim will always split the fractions for the different passenger cars and trucks equally. For example, when 60% of the total amount of traffic are passenger cars, which has three independent categories, Fosim will assign 20% of all vehicles for each category. The remaining 40% will then be freight traffic and this too will be split up in parts of 20% for each category, since there are two categories that are considered as freight traffic.

For the PCE there are two vehicle categories to be considered: category 4 and 5. However, since all freight traffic can be considered as 2,3 passenger cars both categories will be counted as such. Fosim unfortunately does not have information about individual vehicles, so the determination of the PCE-capacity will be done by using the output that Fosim gives. It is assumed that the capacity Fosim gives as output follows from a perfect distribution of freight traffic, which means that the freight traffic factor used as input applies to the output perfectly. When this is assumed it is possible to multiply the corresponding number of freight vehicles by 2,3 to gain the PCE-capacity.

There also needs to be determined how many runs there need to be performed to get accurate results. In order to determine this the confidence interval method is used. With the use of equation $n = \left(\frac{100St_{n-1,\alpha/2}}{dX}\right)^2$ (1 the number of replications necessary to get 98% confidence can be retrieved. The n stands for the number of replications, the S for standard deviation, the $t_{n-1,\alpha/2}$ for the value from the students t-distribution with n-1 degrees of freedom and significance level of $\alpha/2$, the d stands for the percentage deviation of the confidence interval about the mean and the X stands for the mean of the simulations.

$$n = \left(\frac{100St_{n-1,\alpha/2}}{dX}\right)^2 \qquad (1)$$

First, the simulation needs to be run 5 times so that there are starting values for the standard deviation and the mean. With the freight percentage at 10% it turns out that the standard deviation is 328 with a mean of 4326 vehicles per hour. The student t-distribution value is 2,327 (Stanford, 2020) for the 98% confidence, which also means that the d is 2. Filling all these values in leads to a value for n of 77,8 and thus the simulation needs to be run 78 times in order to have the desired level of accuracy.

Fosim also has the function that it can stop a simulation when the speed at a certain detector is lower than a certain threshold. This threshold can be set by the user, as well as the detection point at which this should be determined. The place where problems will occur in this situation is when the on-ramp joins the highway. Upstream from this point a queue will form. When there is a traffic jam the capacity of a highway decreases and therefore it is not interesting to keep on adding more vehicles after the maximum has been reached. The speed at which the threshold is set is 50 km/h and the detection point at which this is measured will be detection point 13. This point is 1000 meters from where the merging lane joins the highway to be sure that the maximum capacity situation has occurred.

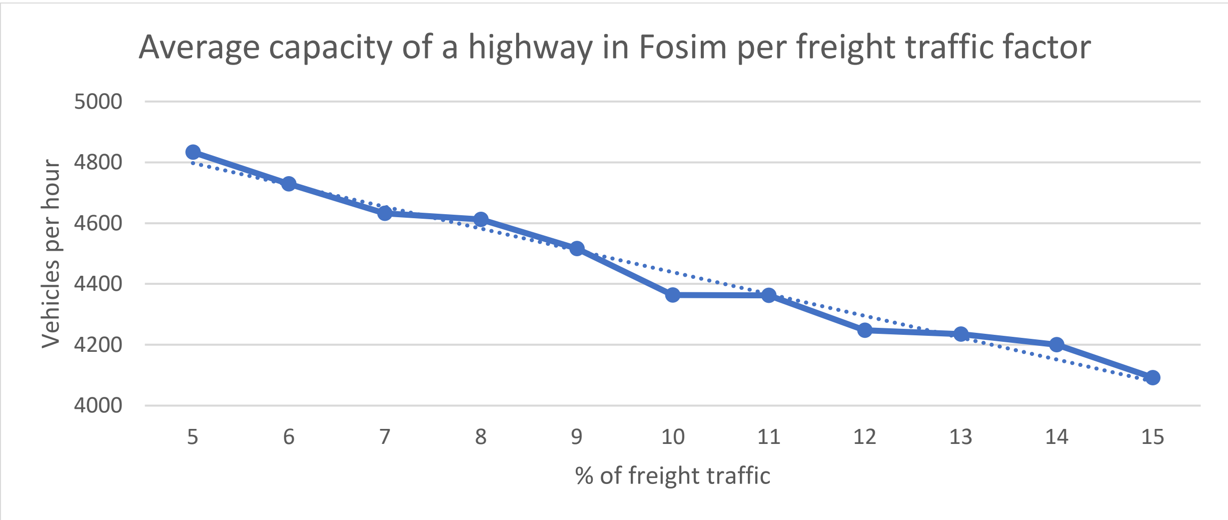


Figure 6 - Average capacity of a highway in Fosim per freight traffic factor

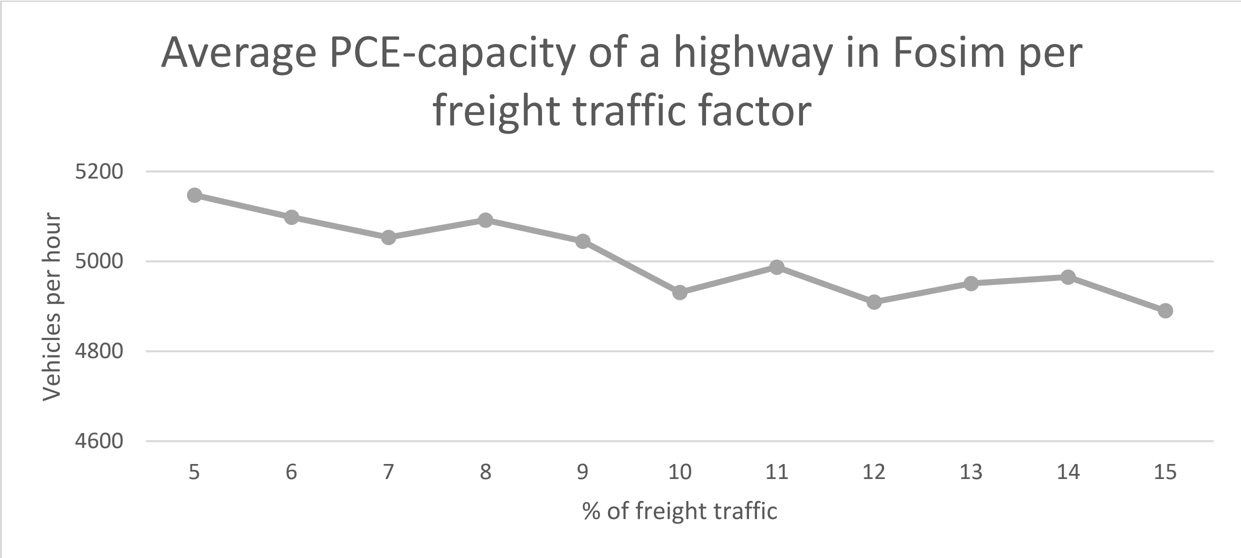


Figure 7 - Average PCE-capacity of a highway in Fosim per freight traffic factor

In Figure 6 can be seen that there is a linear correlation, that is why a trendline has been added to that figure as well. The equation in the form *a*x+*b* for the capacity in Fosim is -71,8x + 5228. This means that the capacity drops by 71,8 per additional percent of freight traffic. In the PCE-capacity a slight decrease in capacity can be seen. This should ideally be identical values, but the fact that there is a decrease might be due to the low significance in the PCE-factor for freight traffic. The equation for the PCE-capacity is -23,2x + 5261

5.1.2. Vissim

What the highway model in Vissim looks like can be seen in Figure 8. This is only the central part of the model, because the highway is much longer than this in both ways. This is done to ensure that the flow at the merging lane is a better representation of reality than when the vehicles have just been spawned by Vissim. Near the end of the highway there is a detection point. This detection point consists of a vehicle travel time collection that measures the time it takes for about one meter. This seems strange, but with this measurement type it is possible to identify individual vehicles and the times of their crossing. Because it is only such a short distance it hardly takes any time to be crossed by vehicles, but in this way the registry of the vehicles is enough. The travel time is irrelevant for this purpose.

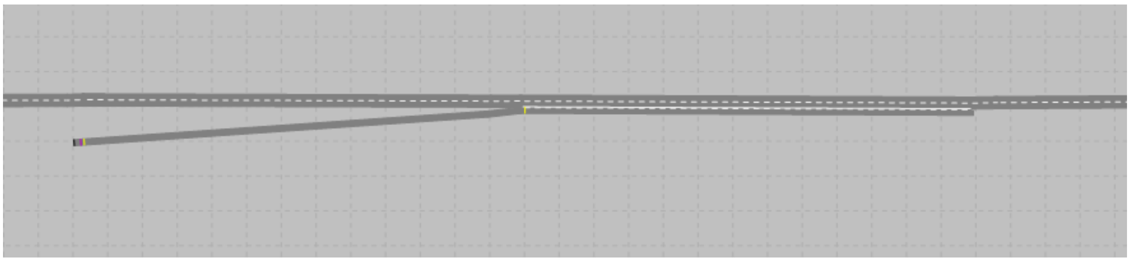


Figure 8 - Highway on-ramp modelled in Vissim

Vissim has three vehicle categories that can be used for the highway model, however, there are very few public transport buses on a highway. Thus the buses vehicle category will not be used for the highway part of Vissim. The vehicle categories for passenger cars and heavy goods vehicles are thus the only one considered in this model. The division between these two categories will be the same as for Fosim, meaning that the percentage of freight vehicles will range from 5 to 15 percent.

Since the input of vehicles is different for Vissim than it is for Fosim a different method has to be used to gain a similar input. In Fosim it is possible to gradually increase the amount of traffic by setting the two extreme points and Fosim would make a line between them with gradually increasing traffic intensity. However, Vissim does not have this feature. Therefore the slope of this line was determined and this turned out to be approximately 50 additional vehicles per hour per 150 seconds. In Vissim the intensity also runs from 2500 to eventually 5000 vehicles per hour on the highway and from 250 to 500 vehicles per hour on the on-ramp.

Furthermore, Vissim had some troubles with the merging of the vehicles coming from the on-ramp. Those vehicles would not switch to the main highway in time and could therefor stack up on the end of the merging lane. This problem was solved by turning on cooperative lane change, which means that vehicles on the highway will move to the left lane when that is possible to make space for the vehicles coming from the on-ramp. After this feature was turned on the stacking on the merging lane only occurred when there already was a traffic jam on the highway itself, which did not have an influence on the capacity downstream.

The determination of the capacity is done in approximately the same way as it is done in Fosim. There a detection point counts the number of vehicles that pass over that point for a period of time and then extrapolates this so the result is in vehicles per hour. Fosim was set up in such a way that for every 120 seconds this would be done. An approximation of this method has been made in Vissim. Vissim can count individual vehicles and also the time at which they pass over the detection point. Because the time of passing is known vehicles can be put into a group of vehicles that pass in a timeframe of 120 seconds. When these results are put into a graph, an example of which can be seen in Figure 9, there can be seen where the maximum capacity has been reached. In the case of the example this maximum is 164 vehicles in 120 seconds, resulting in a capacity of 4920 vehicles per hour. The freight factor for the example is 5%. Unfortunately, Vissim does not have function that a simulation run is stopped when a state of congestion has been reached, which could have saved simulating time. First five initial runs have been performed with a freight traffic percentage of 10% and using the confidence interval method again this resulted in an n of 3,05. This is very little and it is very well possible that an exceptional run will occur and therefore there has been chosen to perform five runs for each freight traffic factor.

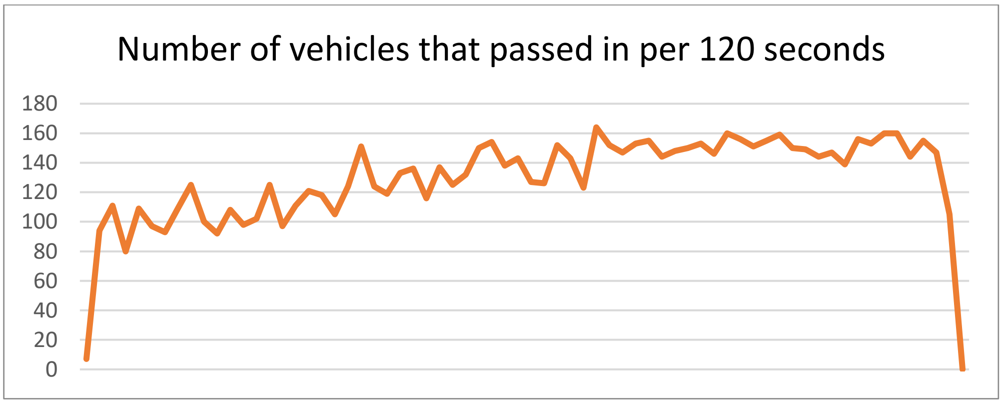


Figure 9 - Example of a graph used to determine the capacity of a highway in Vissim

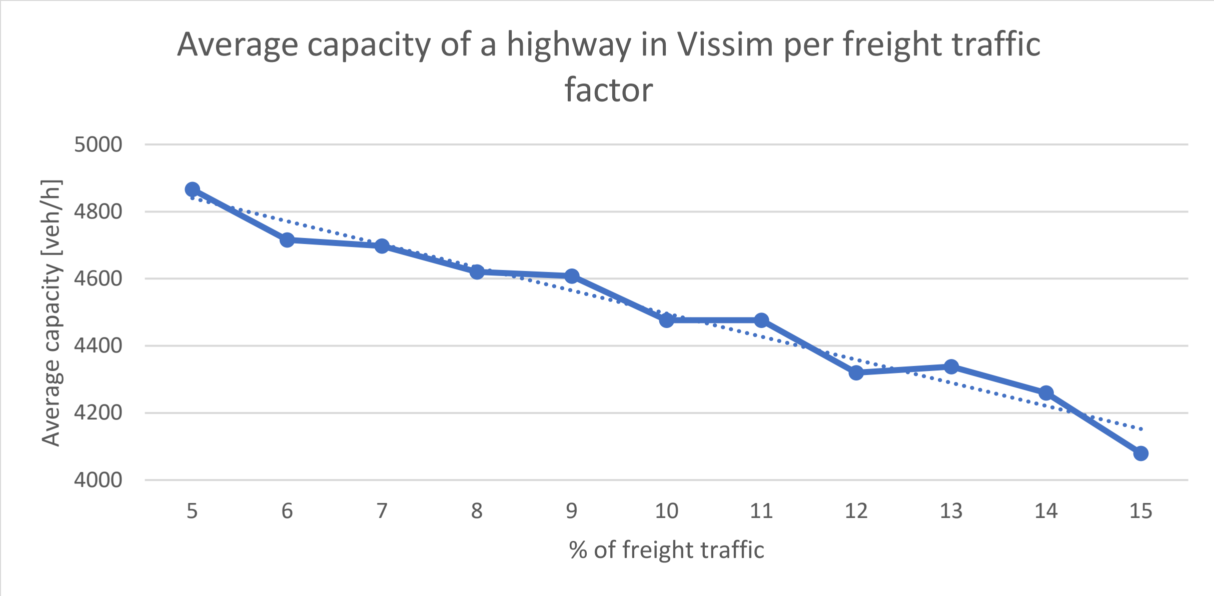


Figure 10 - Average capacity of a highway in Vissim per freight traffic factor

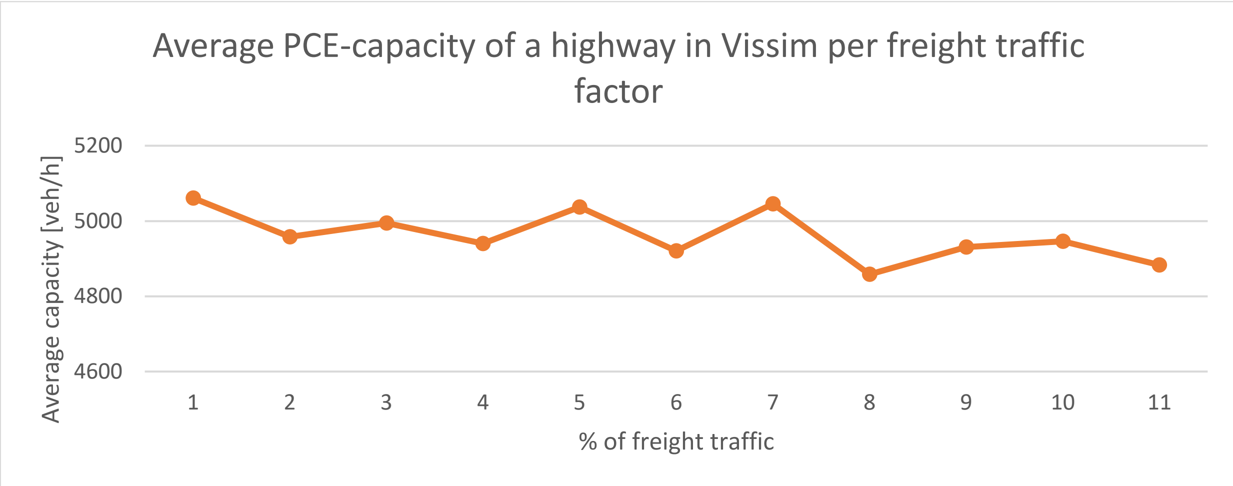


Figure 11 - Average PCE-capacity of a highway in Vissim per freight traffic factor

In Figure 10 a trendline can be seen, because a linear correlation can be seen in the capacity of the highway. The linear equation for this trendline is -68,8x + 5184. This means that the capacity drops by 68,8 per additional percent of freight traffic. In Figure 11 an almost horizontal line can be seen. This was to be expected because the passenger car equivalent capacity should ideally give an identical capacity for each freight traffic factor. There is a slight decrease in capacity visible, however this might very well be due to the fact that the PCE-factor has only two significant numbers, whereas the capacity itself has four. The equation for the PCE trendline is -11,6x + 5089

5.1.3. Comparison highway situation

The results of the two series of simulations have been put into the same graph to show where the similarities or differences might be. The result of this can be seen in Figure 12. The results of both programs are very similar, which is further backed by the fact that the trendlines show a similar equation, which can be seen in Table 10. Fosim has a slightly steeper slope than Vissim, but also a slightly higher capacity for lower factors of freight traffic. The fact that there are minor differences might partly be due to the fact that Vissim does not have a built in capacity function like there is in Fosim and the way this has been solved is not completely perfect. Furthermore, another part of the differences could be due to the relatively small timeframe of 120 seconds in which the passing vehicles are being counted.

It is also interesting to look at the passenger car equivalent graphs, because although they have a less straight line they do show similarities, especially when the freight traffic factor increases. What stands out is the fact that for 12% freight traffic both the values are lower than the values for 13 and 14%, for Vissim even 15% is higher. When it would not matter how much freight traffic there is the line for the PCE-capacity should be a horizontal one, but this is not the case since there is a slight negative trend for both. Thus there can be concluded that when there is more freight traffic the total PCE-capacity will decrease.

Table 10 - Comparison of the equations for the trendlines for the highway situation

Program	Equation	PCE equation
Fosim	-71,8x + 5228	-23,7x + 5261
Vissim	-68,8x + 5184	-11,6x + 5089

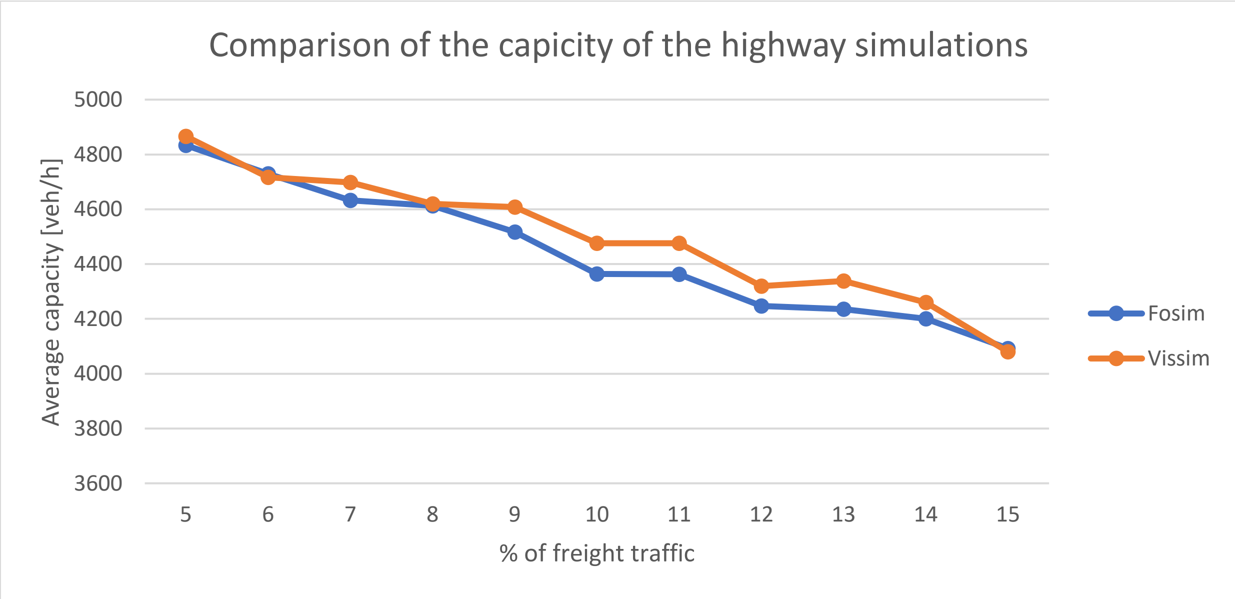


Figure 12 - Comparison of the capacity of the highway simulations

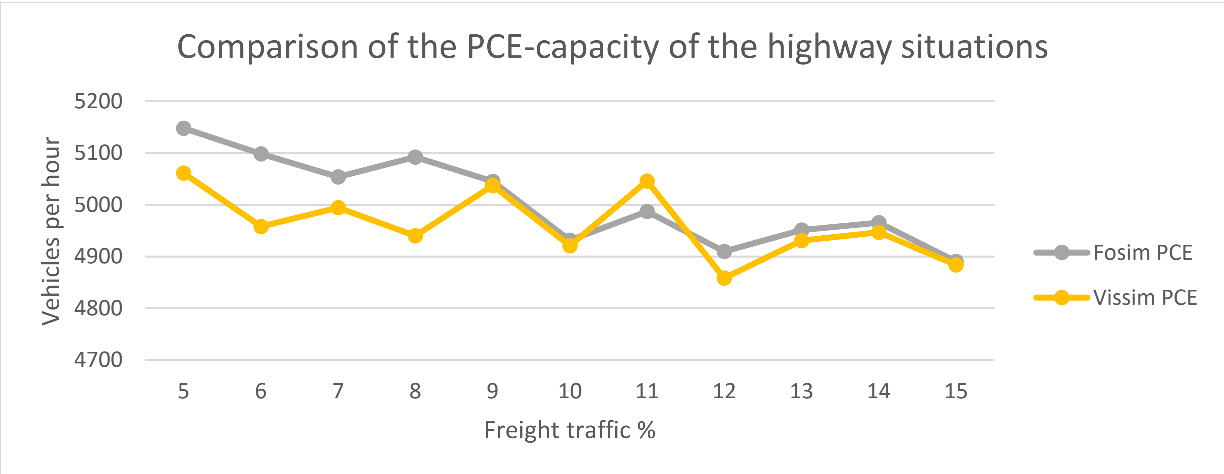


Figure 13 - Comparison of the PCE-capacity of the highway situations

5.2. Urban situation

It is not only interesting to see the effects on the capacity for different freight traffic factors on highways, but also to get an insight into the effects on an urban situation. Traffic on highways is very different from that inside a build-up area. Traffic on highways is much faster and there is much less interaction with other roads. The results will therefore likely be different from that of the highway simulations.

Problems in flow in urban traffic mostly occur at intersections, because it is at points where a road meets another that vehicles will have to wait for each other. This often results in vehicles having to stop completely or at least to slow down considerably. During rush hour this problem intensifies and more and more vehicles will have to wait for each other. Especially busy intersections will have traffic lights to regulate traffic in an orderly fashion and to effectively regulate the flows of traffic. The capacity of these signaled intersections is especially interesting due to the fact that freight traffic generally accelerates much slower than passenger cars and will therefore have an impact on the number of vehicles an intersection can handle.

A simulation will be done to investigate the effects of the freight traffic factor at signalized intersections. Creating a new junction with traffic going in and coming from all directions would resemble a real situation the best. However, because it then ensues four different input flows of traffic that have a lot of conflicting routes it is not feasible to determine the capacity for all of them. Instead, there has been chosen to investigate what the throughput capacity is of one direction going in only one direction. This is because the capacity of the junction is dependent of how many vehicles can pass through a green light period. Therefore, gathering the data for only one lane will be representative for all possible directions since all directions consist of vehicles traveling on one lane. This is assuming that the intersection has maximum one lane per direction. If there would be multiple directions traffic would line up differently with practically all freight traffic in the most right lane. This means that the two lanes should have a different capacity, which is why the range for freight traffic percentages ranges from 0 to 20 percent. This is an increase compared to the highway situation, but with this it is possible to also be able to say something about a situation with multiple lanes.

Freight traffic will have an influence on the capacity, therefore it is interesting to see what the passenger car equivalent capacity is. Vissim only has one category for freight traffic, but Paramics has got three. For Vissim the PCE-value for the freight category will be 2,08. For Paramics the categories will all have a different value: Light good vehicles 1,39, Medium good vehicles 1,79 and heavy good vehicles 2,46 (Ogden, 1992).

As mentioned, there will be only a single road for this situation. This road will be 2000 meters long in order to be sure that vehicles will have settled and there is enough space for the vehicles to form a queue as well. The traffic light will be placed near the end of the road with enough space left for a measurement to be performed after the traffic light, but before the end of the road. The number of vehicles as input will be the same for every simulation, only the fraction of freight vehicles differs between simulations. This number is set at 1000 vehicles per hour. Since the queue will form faster than vehicles will be able to travel through the traffic light it is possible to measure the number of vehicles that pass through per hour to determine the capacity in vehicles per hour. Of course, multiple runs will need to be conducted to be able to say something about the accuracy of the results. A second simulation run can be the hour following on the first of the same simulation. It is necessary to put a warm-up period because vehicles will first need to travel the entire distance from the spawning point until the traffic light. Since this is almost 2 kilometers this takes a while and thus it will take a while for the traffic to form a queue.

In a city there are much more buses than on a highway. These buses will have an influence on the traffic and of the throughput of a certain intersection. However, for this report there is looked especially at the effects of vans being classified in different categories. This does not include buses and because the behavior of buses in a city can be compared to trucks there has been chosen to not make the vehicle input very difficult by adding more vehicle categories and consider buses as trucks. This assumption might have a small influence on the capacity, but since there is especially looked at the relative changes the effects will be negligible.

The traffic lights for the intersection also need to be set-up. The cycle for this will be equal for both programs, so that the data can be compared to each other. This can be achieved, because in both programs it is possible to set up a cycle in great detail. This great detail is not really necessary for this report, since it only is one straight road with no options to go another way than straight on. This makes it possible to have a very simple cycle of 60 seconds. Of those 60 seconds half of the time the light will be on red, which means that it will be green for 27 seconds and yellow for 3 seconds before it becomes red again.

5.2.1. Vissim

The model in Vissim is a straight road with a length of approximately 2000 meters. The traffic light has been placed with the detector close behind it. The detection is in the same way as for the highway part of Vissim. This means that the detector registers every single vehicle and the time at which they cross the detection point. Again the travel time that is measured is irrelevant, but in this way it is possible to detect single vehicles. The final part of the model during a run can be seen in Figure 14.

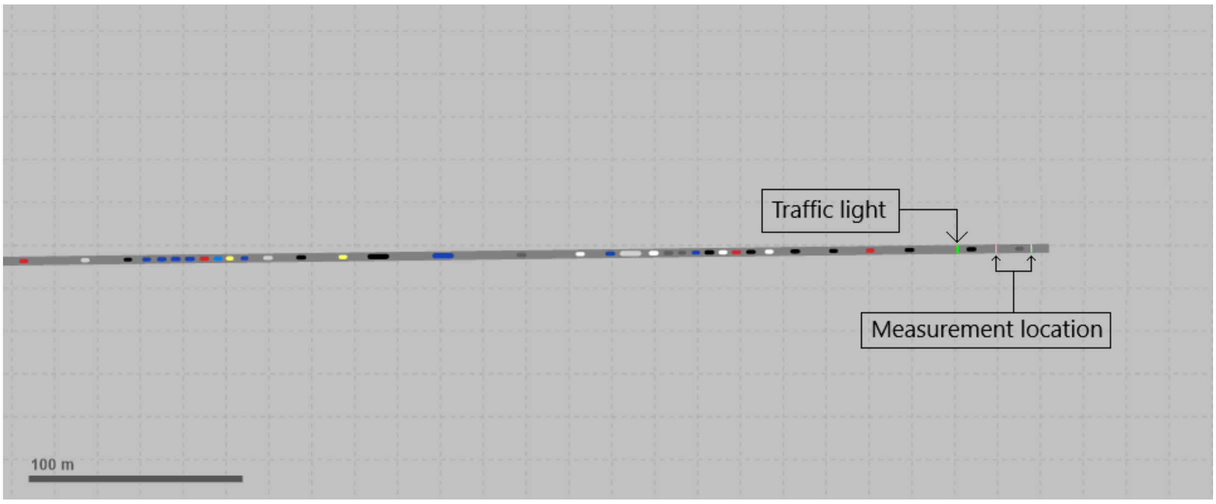


Figure 14 - Model of the urban situation in Vissim

The capacity curve for a highway is dependent on how well the flow is on that highway. The capacity is dependent on the speed of the vehicles driving on it. The capacity increases when the speed of a busy highway goes down to a certain point, which the maximum capacity. Once the traffic starts to jam and there is no continuous flow anymore, the capacity decreases. For highways this is very important to consider and therefore every run needs to start from the beginning again. However, for the urban situation this mechanism does not occur. It is solely about how many vehicles can pass over an intersection and the assumption for this situation is that there is a long enough queue that it cannot dissolve quick enough for the line to disappear. This makes it possible to let the simulation be multiple hours and every hour can then be considered a single run, since the queue necessary will never clear. All the vehicles that have passed in one hour will deliver the capacity in vehicles per hour, so there is no need to perform any further calculations on that.

The amount of vehicles as input and the warm-up period also need to be determined before the simulations can be performed. The input needs to be high enough in order for the queue to form in the beginning and to not clear when the simulation is running for a while. In Vissim this number has been determined at 1000 vehicles per hour. The forming of the queue takes some time since the vehicles first have to cover the distance between the spawning point and the traffic light and once they are there they also need to form a queue that is big enough. The warm-up time has therefore been set at 10 minutes, or 600 seconds. At this point there will always be a queue and thus the simulations will deliver constant data.

Again there will have to be determined how many runs, or in this case hours, there need to be performed to get the confidence necessary. For this the simulation will be run for five hours after the warm-up period. This gives five different capacities with an average of 933 vehicles per hour and a standard deviation of 3,2. Using equation $n = \left(\frac{100St_{n-1,\alpha/2}}{dX}\right)^2$ (1) again with the same values for t (=2,327) and d (=5) this delivers that for this simulation to have enough confidence it needs to be run 0,025 times. This is not feasible and because one simulation might give an extreme value there has been chosen to perform the simulation for each different freight traffic factor for five hours, which comes down to five runs.

In Figure 15 a trendline can be seen, because a linear correlation can be seen in the capacity of the signalled lane. The linear equation for this trendline is -4,59x + 984. This means that the capacity drops by almost 5 vehicles per additional percent of freight traffic. In Figure 16 an increasing line can be seen. This PCE-capacity, which is represented by the line, increases by almost five per additional percent of freight traffic. The exact equation for the PCE-trendline is 4,9x + 982. This was expected to remain approximately the same value, meaning a slope factor of close to 0. The difference in this might be caused by the fact that the PCE is an old value whereas Vissim considers more modern traffic for which the PCE for a truck might be lower due to improved performance and thus a smaller difference with passenger cars.

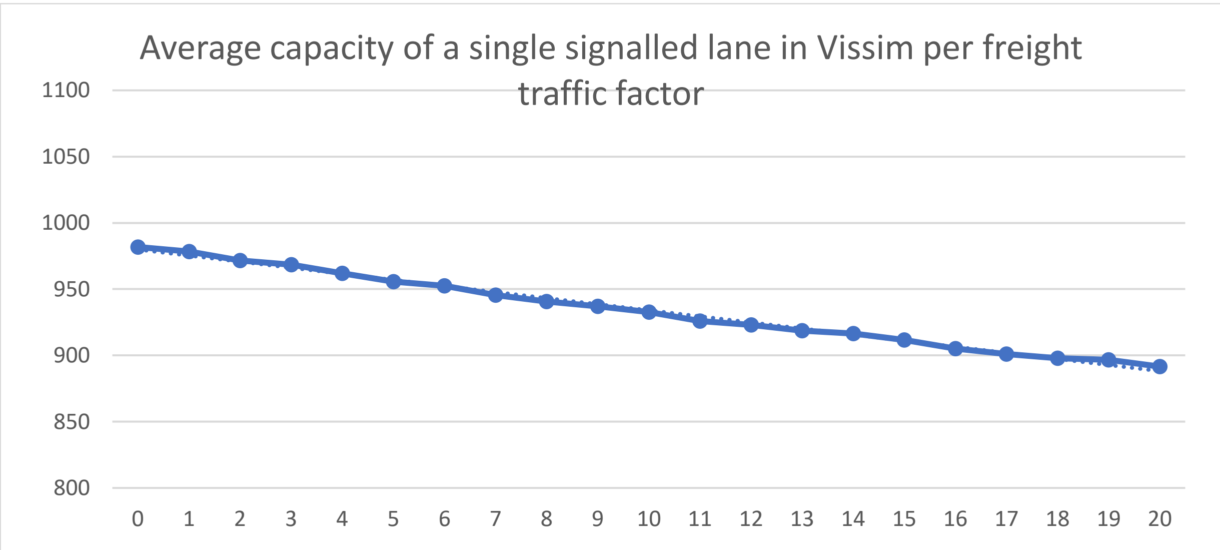


Figure 15 - Average capacity of a single signalled lane in Vissim per freight traffic factor

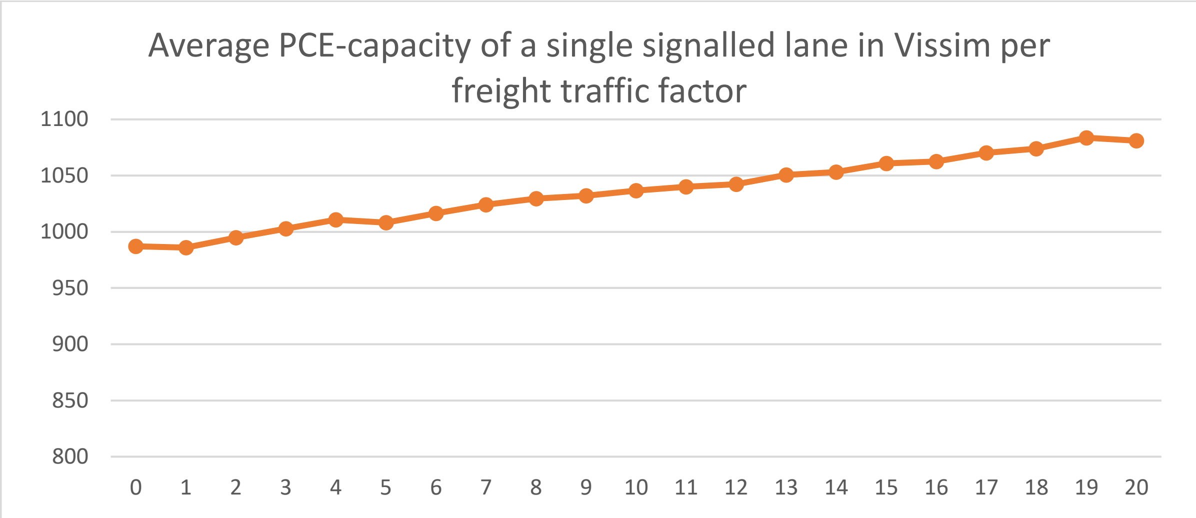


Figure 16 - Average PCE-capacity of a single signalled lane in Vissim per freight traffic factor

5.2.2. Paramics

The model in Paramics is also a straight road with a length of approximately 2000 meters. However, the road is divided up into 4 different road sections. The first sections is very short and is purposely created in order for the spawning of vehicles. In Paramics vehicles come from a zone and this zone needs to be around the midpoint of the road it spawns the vehicles on, which is why this section is only very short. The last section resembles the first section, except for the fact that it is not the origin of the vehicles but the destination. The second section takes up the most length and is from the end of the origin section until the traffic signal. The third section is a small section on which the vehicle measurement takes place and goes from the signal to the destination section.

Paramics has the option to count the amount of traffic per link. As mentioned already in the previous section, the measuring of the vehicles takes place on the third section of the model between the signal and the destination section. Paramics even distinguishes vehicle classes that pass over the measuring link, which makes it very easy to check how much freight traffic actually passes.

There are multiple freight traffic vehicle categories in Paramics that can be used as an input. As has been done by the Fosim vehicle input, there has been assumed that there is an equal division between the freight vehicles. For example, this means that for the situation with 15% freight traffic all three categories of freight traffic in Paramics will attribute 5% to the total amount of traffic. For some cases this means that a third of a percent would be the input. To get this the percentages have first all been multiplied by three, also the passenger car category. Then using the balance option in Paramics the input is automatically adjusted so that the total input is 100, so the vehicle input would not actually be three times as high.

Initially, a vehicle input of 1000 was chosen, as has been done for the urban situation in Vissim. However, it turns out that the vehicle throughput is higher in Paramics than in Vissim, which is the reason why for Paramics the vehicle input is 1250 vehicles per hour. The warm-up time has been set at 30 minutes after which the model runs for one hour in which the data is gathered.

Unlike the model in Vissim, which can run for a very long time, the model in Paramics can only run for two hours due to limitations in the license. This also means that the way of gathering the data like was done in Vissim is not possible for Paramics. In Paramics the model will need to be run multiple times per freight traffic factor to get enough data to know its certainty. To determine this confidence interval equation $n = \left(\frac{100St_{n-1,\alpha/2}}{dX}\right)^2$ (1) will be used once again. Once more, the initial freight traffic factor will be set at 10 percent. The resulting output of five runs generates an average capacity of 998 vehicles per hour with a standard deviation of 6,5. Filling this into the equation results in 0,09 runs that would need to be performed. This is a very low number and to prevent the event of an extreme case as this single run there has been chosen to run the simulation five times per freight traffic factor.

In Figure 17 a trendline can be seen, because a linear correlation can be seen in the capacity of the signalled lane. The linear equation for this trendline is -5,97x + 1063. This means that the capacity drops by nearly 6 vehicles per additional percent of freight traffic. In Figure 18 a very slightly increasing line can be seen. This PCE-capacity, which is represented by the line, increases by two per additional percent of freight traffic. The equation for the trendline for the PCE-capacity is 2,1x + 1059

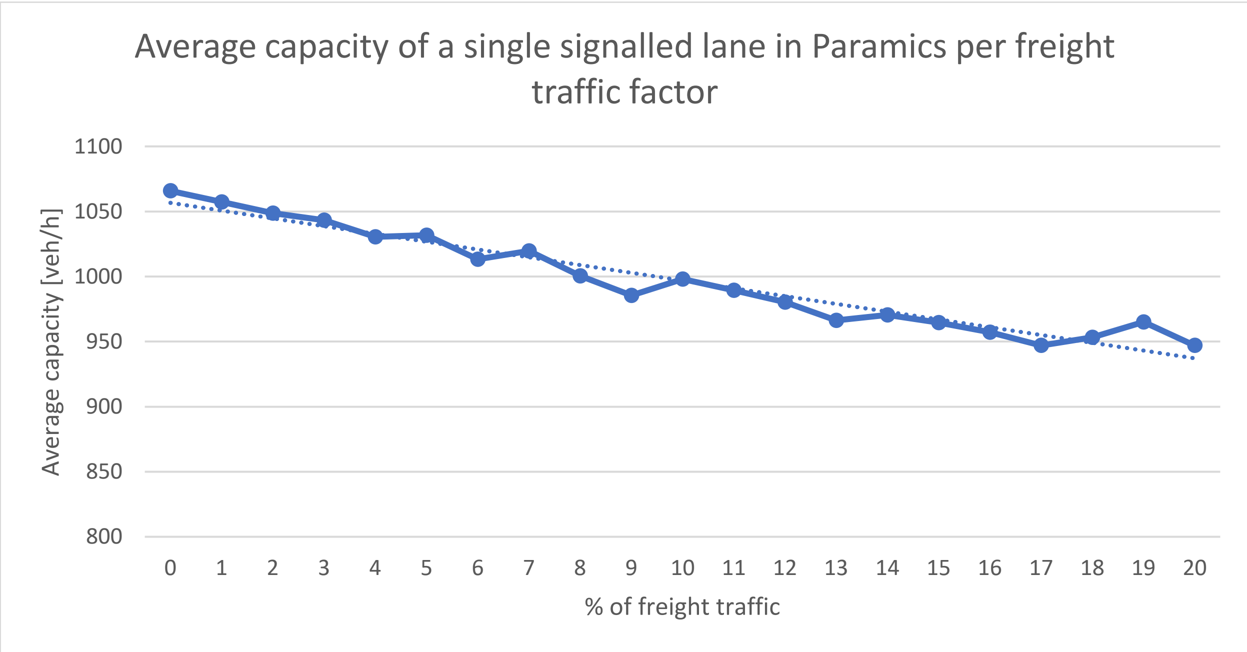


Figure 17 - Average capacity of a single signalled lane in Paramics per freight traffic factor

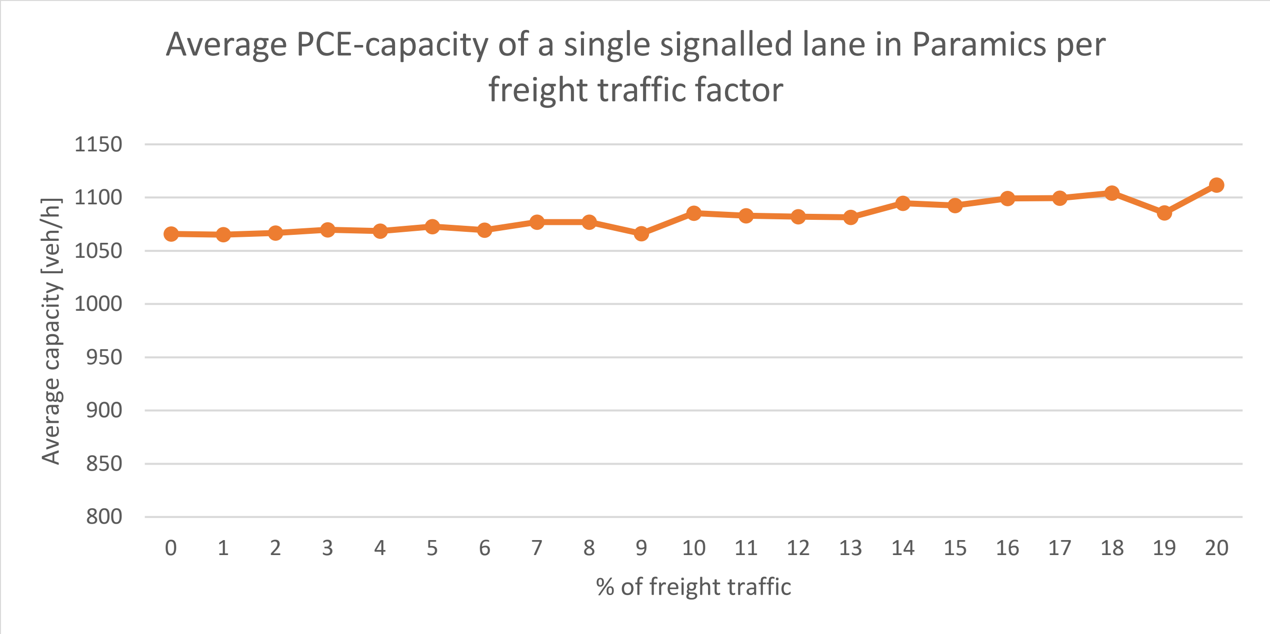


Figure 18 - Average PCE-capacity of a single signalled lane in Paramics per freight traffic factor

5.2.3. Comparison urban situation

The results of the two series of simulations have been put into the same graph to show where the similarities or differences might be. The result of this can be seen in Figure 19. When looking at the figure it immediately stands out that the capacity in Paramics is higher than it is in Vissim. However, when there is looked at the slope there is not such a big difference. The decrease in capacity is quite similar for both programs. Furthermore, it stands out that the line Vissim shows is much smoother than the line of Paramics. This might be due to the fact that Paramics has three different freight categories and due to the relatively low amount of replications an unfortunate placement of the slowest vehicle class might already have quite a big influence. For Vissim there is only one freight vehicle category and thus this might have less of an influence.

The reason the two programs differ by around 75 vehicles per hour could be explained by the fact that the acceleration of the vehicle classes in Paramics is generally higher than that it is in Vissim. Of the three freight categories in Paramics only one has a lower value for acceleration than the freight category in Vissim. Besides, the acceleration for passenger vehicles is higher in Paramics as well. Furthermore, the length of vehicles in Paramics is lower than in Vissim, which allows for more vehicles on the same amount of space. Passenger cars in Vissim are longer than the ones in Paramics. Only the Heavy Goods Vehicles category in Paramics has a higher length than the Vissim freight category, but the HGV make up only a third of the freight traffic in Paramics. All this can also be seen in Table 9.

In Table 11 there is an overview of the trendlines for both programs. What stands out is that the trendlines for the PCE-capacities have a positive slope, which would mean that it is actually preferable for the traffic flow to have more freight traffic. This is opposite of what was expected. This phenomenon can however be explained by the fact that it is a really simplified situation of a signalled intersection. There are no turns to be made or multiple lanes that could have an effect on the flow of traffic. Especially when there are more larger vehicles turns have a negative influence on the capacity. Furthermore, when there are multiple lanes passenger cars do not have to stay behind freight vehicles, but can overtake them which would increase the total capacity.

Table 11 – Comparison of the equations of the trendlines for the urban situation

Program	Equation	PCE equation
Paramics	-5,97x + 1063	2,1x + 1059
Vissim	-4,59x + 984	4,9x + 982

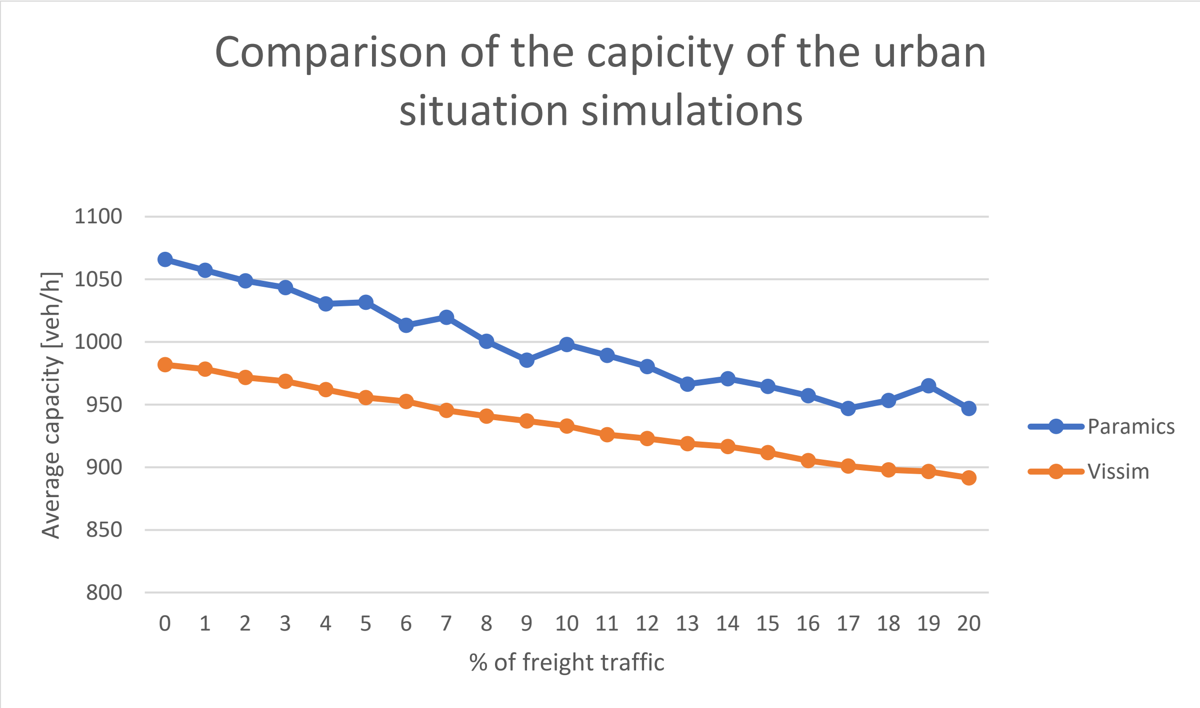


Figure 19 - Comparison of the capacity of the urban situation simulations

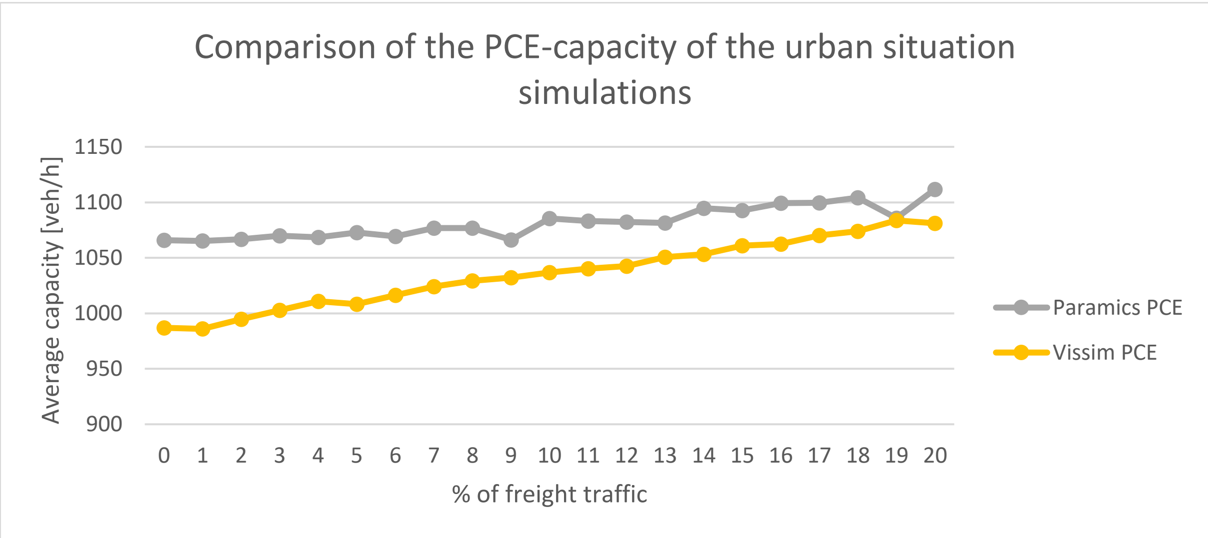


Figure 20 - Comparison of the PCE-capacity of the urban situation simulations

6. Conclusions

In this section there will be looked back at the research question and answers will be given based on the previous chapters. Below the research question will be stated again, which will be elaborated on further in the rest of the section. After that there will also follow some recommendations.

"What is the influence of vehicle classification on the capacity of an analysed road network in a traffic model simulation?"

There is not a direct single answer to this question, because with traffic models many different situations can and will be modelled. Not only the situation matters, but also the simulation program itself, since not all programs simulate situations in an identical way.

However, in order to be able to simulate in a useful way the traffic intensities need to be known. Just the intensities alone are not useful, it also needs to be known what the size or class of vehicle it is. It is possible to measure every vehicle independently. Depending on the way the traffic is measured the length of a vehicle is determined. This individual data is generally immediately put into a classification system that makes impossible to go back to the data for all individual vehicles. This is done by Sweco itself into 13 vehicle categories, but also by the NDW in only 3 or 5 vehicle categories. The majority of the vehicle classes consist of some kind of freight traffic. If a simulation program has different boundaries for determining a vehicle class than the database it uses a model will not deliver results that are completely accurate for that situation.

Traffic simulation programs also have vehicle classes, but different programs all have different vehicle classes. There is not one univeral vehicle classification system. Of the three studied traffic simulation programs Vissim has one freight traffic category, Fosim has two and Paramics has three. This already shows the differences in vehicle classification while only looking at three programs Sweco uses. However, all these programs use the same data from NDW or from Sweco itself as input. This cannot always be done accurately due to the fact that a program might have more vehicle classes than are in the NDW datasets. A division of one of the NDW vehicle classes might have to occur in order for a program to simulate with all vehicle classes. This means that there needs to be estimated as to how many vehicles fit into each category, which could lead to inaccurate results. When vehicle measurements are stored per individual vehicle and not per predetermined vehicle category simulation programs can define vehicle classes more accurately. On the other hand, simulation programs could adapt to the databases and base their vehicle classes on the public datasets. It is also possible for the measurements Sweco performs themselves to use the same classification system as the NDW uses to create unity.

To determine the impact of the change in vehicle categories simulations were performed. As expected, the capacity declined with the increase of freight traffic. For highways this is around 70 vehicles per hour less per additional percent of freight traffic and for the signalled intersection this was only around 5 vehicles per hour less for each additional percent of freight traffic. Looking at these numbers it is visible that for a highway situation the capacity is a lot more sensitive for a change in capacity than an urban situation is.

It is also very interesting to look at the passenger car equivalent (PCE) capacity for both the situations, because with this it is possible to look at the total capacity. If there would be no change in the PCE then it would not really make a difference whether a vehicle is put into one category or another. For the highway situation this resulted in a decrease of capacity of approximately 12 and 24 vehicles per hour less for each additional percent of freight traffic for Vissim and Fosim respectively. The most problematic category of vans make up around 7% of all Dutch traffic, so the capacity could vary by over

100 vehicles per hour when looking at the passenger vehicle equivalent, which can mean a change in capacity of over two percent on highways. For the urban situation the PCE-capacity increases when there is more freight traffic, which seems counterintuitive. These changes in capacity are approximately 2 and 5 vehicles per hour more per additional freight traffic percent for Paramics and Vissim respectively. This leads to a possible change in capacity of up to three percent when vans would be classified differently.

7. Discussion

The models that were used for this research are very basic models. Real situations are much more complex with more turns or intersections. The situations for this research have been kept very simple to make it possible to say something about the vehicle category and not really about the road network itself. In real situations therefore the results of this research will be slightly different from what happens in more complex situations.

There has also been assumed that when there are multiple vehicle categories for freight traffic each of these categories has an equal share. This has also been done for the passenger car categories in Fosim. It is highly unlikely that these relative values also occur on the road. In this research it has been chosen because it makes it easier to compare different freight traffic factors, but for a future research it would be better if there is looked deeper into the difference the different freight vehicle classes make within a program.

The fact that all the Passenger Car Equivalent capacities show a slightly upward line is not what was expected. This might be due to the fact that the situations, especially the urban situation where it occurs, are very basic situations. On an actual intersection vehicles have to make turns, which especially freight vehicles struggle more with than passenger cars. This means that freight vehicles will have a bigger impact on the capacity of that intersection. Moreover, the fact that there is only a single lane is not entirely representative. The fact that the range of percentages is higher for the urban situation is because with the low percentages a left sorting lane might be realised.

List of figures and tables

8. References

ANWB. (2020, March 11). *Invoegen*. Opgehaald van ANWB: https://www.anwb.nl/verkeer/veiligheid/invoegen

CBS. (2020, 06 20). *Aantal wegvoertuigen blijft stijgen*. Opgehaald van CBS: https://www.cbs.nl/nl-nl/nieuws/2019/14/aantal-wegvoertuigen-blijft-stijgen

CBS. (2020, January 29). *Motorvoertuigenpark; type, leeftijdsklasse, 1 januari*. Retrieved from Centraal Bureau voor de Statistiek: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82044NED/table?ts=1580833310590

Dijker, i. T., & Knoppers, i. P. (2006, March 5). *Fosim 5.1 Gebruikershandleiding.* Opgehaald van Fosim.

E. Kuiper, D. N. (2013). *Voertuigcategorieën en gewichten van voertuigcombinaties op de Nederlandse snelweg op basis van assen-combinaties en as-lasten.* TNO.

FHWA, F. H. (2016). *Federal Highway Administration Traffic Monitoring Guide.* U.S. Department of Transportation.

Goemans, I. J., Daamen, D. W., & Heikoop, I. H. (2011). Handboek Capaciteitswaarden Infrastructuur Autosnelwegen (CIA).

NDW. (2013, January 17). NDW interface beschrijving. Opgehaald van https://www.modelit.eu/modelit/restricted/NDW%20interface%20beschrijving%20v1.2%20final.pdf

NDW. (2019, February 3). *Actuele verkeersgegevens*. Retrieved from Nationale Databank Wegverkeersgegevens: https://www.ndw.nu/pagina/nl/4/databank/31/actuele_verkeersgegevens/

NDW. (2020, March 2). *Actuele verkeersgegevens*. Opgehaald van NDW: https://www.ndw.nu/pagina/nl/4/databank/31/actuele_verkeersgegevens/

Ogden, K. (1992). *Urban Goods Movement: A Guide to Policy and Planning.* Burlington, VT: Ashgate Publishing Company.

Pitney Bowes. (2020, March 10). *Link speed behavior in Paramics network*. Opgehaald van Pitney Bowes: https://support.pitneybowes.com/SearchArticles/VFP05_KnowledgeWithSidebarHowTo?id=kA180000000CoPMCA0&popup=false;&lang=en_US

Rijkswaterstaat. (2010). *PAE-waarde van vrachtverkeer in relatie tot wegcapaciteit.* Rijkswaterstaat Dienst Verkeer en Scheepvaart.

Rijkswaterstaat. (2017). *Richtlijn Ontwerp Autosnelwegen 2017.*

Rijkswaterstaat. (2020, March 10). *De maximumsnelheid in Nederland*. Opgehaald van Rijkswaterstaat: https://www.rijkswaterstaat.nl/wegen/wetten-regels-en-vergunningen/verkeerswetten/maximumsnelheid/index.aspx

Rijkswaterstaat. (2020, March 3). *Weight in Motion Netwerk Rijkswaterstaat.* Opgehaald van https://www.ilent.nl/binaries/ilt/documenten/publicaties/2013/11/08/overzicht-weegpunten-in-nederland/WIMoverzicht01_tcm334-347083-1.pdf

Stanford. (2020, March 19). *Table of Student t-Distribution*. Opgehaald van https://web.stanford.edu/dept/radiology/cgi-bin/classes/stats_data_analysis/lesson_4/234_5_e.html

Sykes, P. (2010). Traffic simulation with Paramics. In J. (. Barcelo, *Fundamentals of Traffic Simulation* (pp. 131 - 171). New York: Springer-Verlag.

Willekens, M. (2016). *Verkeerslichten in Nederland 2015.* Breda: DTV Consultants.