Impact of data on the transport sector? Future business models for Mobility as a Service (MaaS)

Thijs Van den Brande

Supervisors: Prof. dr. ir. Sofie Verbrugge, Prof. dr. ir. Didier Colle
Counsellor: Dr. ir. Marlies Van der Wee

Master's dissertation submitted in order to obtain the academic degree of
Master of Science in Industrial Engineering and Operations Research

Department of Information Technology
Chair: Prof. dr. ir. Bart Dhoedt
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Last but not least I want to thank my family and friends for the unconditional support during the process of writing this master dissertation.

Thijs Van den Brande, June 2017

Impact of data on the transport sector? Future business models for Mobility-as-a-Service (MaaS)

By
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Abstract – The mindset of the younger generation on mobility is changing. Instead of owning a car, they would like to buy services to travel from a specific starting point to a destination. In addition to this, new transportation modes like bike and car sharing are growing steadily. Because of these changes, the focus could or should shift from a system focusing purely on the transportation itself to a multi-modal system that focuses heavily on the end-users and a better service level. That is exactly what the concept Mobility-as-a-Service (MaaS) is about. MaaS is a system that will ensure convenient switching between different transportation modes. The challenge will be to construct a business model for a MaaS provider in the current mobility ecosystem. This paper will explain the steps that need to be taken to develop such a business model, and will develop a software model that simulates the MaaS ecosystem. The goal of this paper is to find an answer on the following question: "Is offering mobility packages enough to create a valuable business model for a MaaS provider? Are information services highly necessary to create an economically viable business model?". The two most influential parameters on the business model are the discount received from the transport suppliers and the discount given to the travelers. The setup of these parameters shows what the strategy of the MaaS provider is. If the discount given to the travelers is set to the same percentage as the discount received, the MaaS provider wants to maximize its yearly profit in the short-term. A long-term strategy is chosen when the MaaS provider sets the discount it gives higher than the discount it receives, then the customer base will increase significantly until a saturation point is reached. This increase in customer base will increase the yearly profit in the long-term. This paper concludes that when the Maas provider receives a purchase discount of 5% or higher, it is capable of constructing a profitable business model without offering the information services. Including information services on the other hand is recommended because this service does not have a significant cost in comparison with the extra revenue it could generate.

Keywords – Mobility-as-a-Service (MaaS), multi-modal system, business model, implementation model, techno-economics, mobility services, information services

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***Abstract* – The mindset of the younger generation on mobility is changing. Instead of owning a car, they would like to buy services to travel from a specific starting point to a destination. In addition to this, new transportation modes like bike and car sharing are growing steadily. Because of these changes, the focus could or should shift from a system focusing purely on the transportation itself to a multi-modal system that focuses heavily on the end-users and a better service level. That is exactly what the concept Mobility-as-a-Service (MaaS) is about. MaaS is a system that will ensure convenient switching between different transportation modes. The challenge will be to construct a business model for a MaaS provider in the current mobility ecosystem. This paper will explain the steps that need to be taken to develop such a business model, and will develop a software model that simulates the MaaS ecosystem. The goal of this paper is to find an answer on the following question: "Is offering mobility packages enough to create a valuable business model for a MaaS provider? Are information services highly necessary to create an economically viable business model?". The two most influential parameters on the business model are the discount received from the transport suppliers and the discount given to the travelers. The setup of these parameters shows what the strategy of the MaaS provider is. If the discount given to the travelers is set to the same percentage as the discount received, the MaaS provider wants to maximize its yearly profit in the short-term. A long-term strategy is chosen when the MaaS provider sets the discount it gives higher than the discount it receives, then the customer base will increase significantly until a saturation point is reached. This increase in customer base will increase the yearly profit in the long-term. This paper concludes that when the Maas provider receives a purchase discount of 5% or higher, it is capable of constructing a profitable business model without offering the information services. Including information services on the other hand is recommended because this service does not have a significant cost in comparison with the extra revenue it could generate.**

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I. INTRODUCTION

The evening traffic jams in 2016 were on average 16 kilometers longer than in 2015 [1] and the number of vehicles in Belgium increased with 16.8% from 2006 to 2016 [2]. The average amount of travels per day is 2.74, 69.62 percent of those travels happen by car [3]. Every action taken to lower the travels made by car will improve the smoothness of every travel remarkably. These increases cause the amount of time employees waste in traffic to grow, the emission to rise, roads to fray through faster, etc. To prevent the increase of all these negative statistics, the mobility sector needs to take a different path. A future direction the mobility sector can take is to move away from individual transport modes towards a multi-modal system. Mobility-as-a-Service (MaaS) is such a system, which offers end-users monthly "mobility packages" for a fixed fee [6]. One integrated payment system will make payment easier for the customers and as a side-benefit simplifies the collection of travelling data. The mobility problems (traffic jams, environmental concerns, etc.) could benefit immensely from this travel information gathered. Travel information can be derived from the collected data and used to convince drivers to take public transport and to reduce roadway and parking congestion. How to switch from the regular mobility environment to a MaaS ecosystem and its most likely consequences, will be one of the topics of this paper.

Existing research about MaaS mainly focuses on explaining MaaS on a conceptual level. The transport from a human end-user perspective, i.e. travel instead of transportation, is discussed in detail by Giesecke et al. [4]. Alongside the nature of travel, also the sustainability of MaaS is being addressed. Finger et al. explain the concept MaaS and what it could develop into in the context of congestion problems and changing mobility patterns [5]. Benefits of MaaS like door-to-door journeys and simple and easy customer experience are described in [6]. An overview of a possible platform's architecture is given by [7] together with an explanation about how to bring mobility service supply and demand together in a common marketplace. In [8], an analysis is made about the evolution that needs to happen towards multi-modal mobility providers.

This paper focuses on the business model of a MaaS provider instead of the concept MaaS. Not only are the stakeholders that will be part of a MaaS ecosystem described, but also how they collaborate with each other and what their influence will be on the business model of a Maas provider.

A MaaS provider offers mobility packages and hence moves away from individual transport modes. Customers can buy mobility packages according to their mobility needs. All these packages combine options from different transport providers into a single mobility service, removing the hassle of planning and paying all the different transport providers separately.

Customers of a MaaS provider also generate a significant amount of data about their mobility behavior. Valuable information, like travel patterns, can be extracted out of this data. The difference between the information gathered by a MaaS provider and a regular transport provider is situated in the scope of the information. Regular transport providers only collect information about the usage of that particular transport mode by a specific customer. This hence does not tell anything about the general traveling behavior of that customer. It goes without saying that general traveling behavior has much more value. It is clear now that the value of MaaS goes beyond offering smooth mobility services to customers, it also allows providing information services, targeting longer horizons and allowing to identify trends that can be used for strategic decision making. The degree of importance of those two services is researched in this paper. Therefore, the goal of this paper is to find an answer to the following research question: "Is offering mobility packages enough to create a valuable business model for a MaaS provider? Are information services highly necessary to create an economically viable business model?".

II. Business model for a MaaS provider

The MaaS ecosystem used in this paper is one where all the transport resources are bought externally, making the MaaS provider a kind of middleman between the different transport providers and the travelers. The business model canvas of Alexander Osterwalder was used to clearly visualize this business model [9]. How to construct a business model was researched through business models from other industries and from transport providers, such as a car sharing company [10].

A. *Stakeholders of Mobility-as-a-Service*

A MaaS ecosystem consist of a range of different stakeholders, each of whom play an important role. The stakeholders depend on each other to be able to function properly. The MaaS provider, the travelers, the different transport providers and the data-interested institutions form the main stakeholders of a MaaS ecosystem.

A MaaS provider works together with all the other stakeholders. Different kinds of mobility packages will be created by the MaaS provider to make sure that as many travelers as possible can satisfy their needs using one of the offered packages. The travelers and the MaaS provider are not only linked to each other through the mobility aspect but also through the information aspect of MaaS. Traveling data about the travelers is collected by the MaaS provider by using an integrated payment system together with an application that stores location data of the travelers.

To be able to use the services of the transport providers, a MaaS provider needs to conclude a contract with those providers, in which a specific price, mostly per distance or time unit, is negotiated. The information service also plays a role between these two stakeholders. The transport providers could benefit a lot from the traveling patterns that are extracted out of the raw data collected by a MaaS provider.

The link between the MaaS provider and the other interested institutions is solely based on the information aspect of MaaS. Governments, for example, can be willing to pay a price for travel pattern information so they can adjust their roadmaps, road taxes, etc.

Besides the stakeholders mentioned above there are some other companies that a MaaS provider works with to be able to function properly. A cloud provider is one of them, it is quite clear that the amount of raw data collected will be enormous, and needs to be stored. Analyzing the data is also done by a third party. Two other companies that work for the MaaS provider are the developer and installer of an integrated payment system and last but not least the developer of the software (app, website) used by a MaaS provider.

B. *Cost model for a MaaS provider*

The costs that a MaaS provider encounters will originate from two different kind of services: the mobility services and the information services. The different costs that a MaaS provider entails, shown in Figure 1, are subdivided into three categories: direct costs, shared costs or common costs [11].

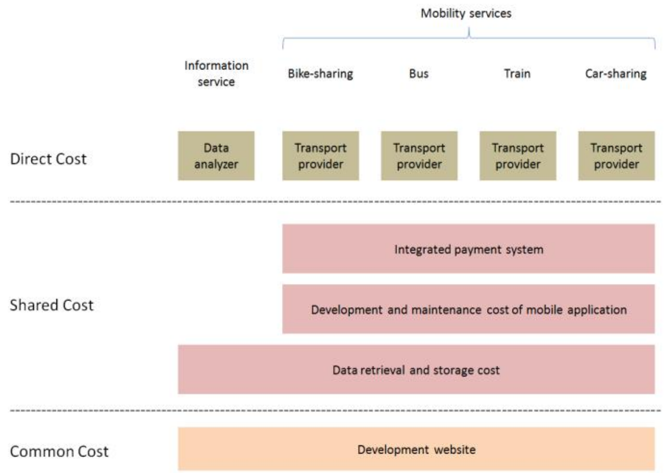

Figure 1: Categorization of the costs of a MaaS provider

To account the different costs to both mobility and information services, cost allocation will be applied, the fully allocated cost (FAC) method is used [11]. Cost allocation is needed to provide enough information to make business decisions in both the long and short term, it is also an important planning tool for increasing profits and reducing costs. The total transport cost is a direct cost that is allocated to the different transport modes per kilometer. The second direct cost is the cost to analyze the data, which is allocated by using a single travel as cost driver. The cost of installing the integrated payment system is a shared cost with the amount of installed systems as cost driver. From the storage and retrieval of data cost, 90% is allocated to the information services and 10% to the mobility services. The last shared cost is the cost of developing and maintaining the mobile application, this is a fixed cost. Hence this cost will be evenly allocated over all four mobility services. Finally, there is one common cost, the cost to develop the website, which can be seen as an overhead cost. This cost will be evenly divided amongst the information and mobility services.

C. Revenue model

To compensate the cost that a MaaS provider has, revenue needs to be generated. This revenue originates from both the mobility and the information services offered.

The revenue generated by the mobility services is solely originating from the mobility packages that are sold to the travelers. There are two aspects about these mobility packages causing a MaaS provider to make some profit. First, by purchasing transport services from the separate transport providers in bulk, a MaaS provider gets some discount. Now the MaaS provider has a choice to make: is the received discount used entirely to give as discount to the travelers or does the MaaS provider keep a part of the discount as a direct profit source? The second way a Maas provider generates profit is because on average the customer will not use all the transport services in the mobility package that he or she bought, even if he or she paid for it.

The second source of revenue are the information reports that are sold to data-interested institutions. Some examples of data-interested institutions are: transport providers such as De Lijn and NMBS, local, regional and national authorities and cities in general.

III. Simulation model

A model was constructed to simulate the MaaS ecosystem, the implementation of the model is done in JAVA. The different costs used in this model are based on the costs that a MaaS provider would encounter when located in Flanders, Belgium. The goal of this simulation model was to get a clear view on the degree of importance of the two services that a MaaS provider can offer. The travelers are simulated by some characteristics (age, employment, etc.) and an associated week schedule, representing their weekly traveling needs. Those traveling needs are then assigned to a specific transport mode, to get a detailed overview of the travelling needs per transport mode of this particular traveler. This is done by taking into account the preference of a traveler, which can be a minimization of consumed time, a minimization of cost, a minimization of a weighted function based on both time and cost, or a choice for the most environmental friendly option.

The MaaS provider has to decide which mobility packages to construct and offer to this group of travelers. A MaaS provider would want to convince as many travelers as possible to become real customers of its services. Hence, the best combination of mobility packages needs to be found to offer to the travelers. To solve this optimization problem a linear program (LP) was constructed and solved with the Gurobi solver in JAVA [12]. First an optimal model was constructed to get the best combination of mobility package to offer to the travelers:

$\mathrm{C_i} =\ \mathrm{i^{th}}$ combination of possible mobility packages

$\mathrm{M} =$ amount of different combinations of the possible mobility packages

$\mathrm{nCustomers_i} =$ number of travelers that became customers after offering combination i

Maximize:

$$\sum_{i=1}^{M} nCustomers_i * C_i$$

Subject to:

$$\sum_{i=1}^{M} C_i = 1$$

$$\mathrm{C_i} \in \{0, 1\}$$

The LP itself is not complicated but the amount of combinations and number of travelers make the calculation very time consuming. To try to reduce the calculation time, a sub-optimal model was constructed that was used to reduce the amount of mobility packages that are offered as possible options to choose from to the optimization model. Applying this procedure reduces the amount of combinations to be checked with a factor of 18, which takes significantly less time to calculate.

To test how valuable this business model is, the exact group of travelers that become customers needs to be obtained, to be able to calculate the costs and revenues of the MaaS provider. This is done by linking the mobility packages to the travelers. Two conditions need to be met in order to get a positive result in the linking process: (1) fulfilling the majority of the traveling needs of the traveler and (2) having a price that is lower than the combined pricing of the separate transport providers.

IV. Analysis of different scenario's

Now that the model is constructed in JAVA, it can be used to simulate different scenarios, to see which parameters have a significant impact on the business case. What this impact exactly is, will be investigated by ranging the influential parameters of the model. These parameters are: the discount given to the travelers (*travelersBenefit*), the discount received from the transport suppliers (*purchaseDiscount*), the number of sub-lists per transport mode used to represent the traveling needs of the population (*nOfSublists*) and the number of mobility packages offered to the travelers (*nOfPackages*).

A. Reference scenario testing

First a reference scenario is constructed, because the impact of the parameters mentioned above were investigated by ranging them in this reference scenario. This scenario consists of a population size of 100 000 travelers and a maximum statistic to represent the traveling needs of a group of travelers. The population size was set to 100 000 because the results stagnate from this size. Using the maximum as the statistic to represent the traveling needs of a group turned out to be the best option when aiming for maximizing the number of travelers that become customer of the MaaS provider.

B. Varying the discount received by the MaaS provider and the discount given to the travelers

The impact of both these variables is checked by varying them in a specific interval, first separately, then together. The focus of this investigation lays on the impact of both the variables on the mobility aspect of the MaaS provider, more specifically on the mobility costs and revenue of the MaaS provider.

If only the discount that a MaaS provider gets from its transport suppliers (*purchaseDiscount*), is varied and the discount it gives to its customers (*travelersBenefit*) is fixed, the number of travelers that become customers of the MaaS provider stay the same for every scenario simulated. The yearly profit increases linearly with the purchase discount received. The mobility cost of the MaaS provider stays the same for every scenario simulated because in all the simulations the same group of travelers became actual customers. If the mobility costs stay the same and only the discount changes on that particular cost, then obviously, the yearly income will increase linearly according to the discount received.

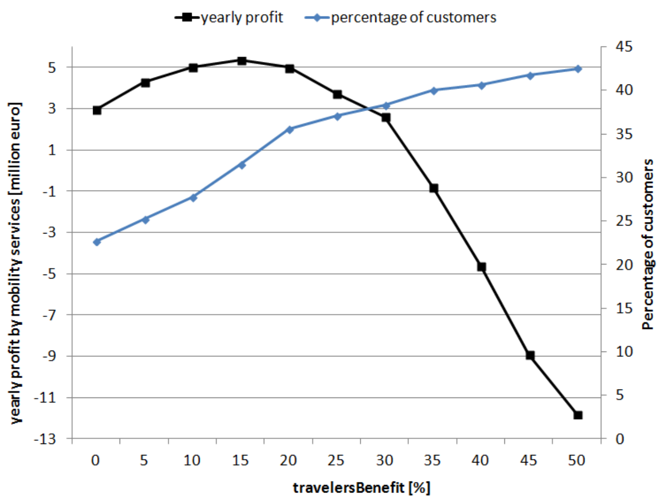

Figure 2: Yearly profit Maas provider with varying travelersBenefit

When investigating both the increase of percentage of travelers that become customers and the yearly profit generated, when the *purchaseDiscount* is fixed, the results in Figure 2 are obtained. This Figure shows that there is an optimal point in terms of yearly profit. First, the yearly profit rises together with the percentage of travelers that become customer. But when the *travelersBenefit* becomes larger than 15%, the yearly profit starts to decrease very fast. At the point where both the *travelersBenefit* and the *purchaseDiscount* are equal to 15%, the MaaS provider uses the discount it gets from the transport providers entirely to give to the travelers as discount. When the *travelersBenefit* is lower than the *purchaseDiscount*, the MaaS provider will keep a part of the *purchaseDiscount* as a direct profit instead of giving the discount entirely to the travelers. This direct profit is reflected in the slope of the black graph between two points.

Figure 3 allows to conclude about the yearly profit of the MaaS provider, when both the *purchaseDiscount* and the *travelersBenefit* are varied. A graph of the yearly profit for every possible value of the *travelersBenefit* is shown: the lower the *travelersBenefit*, the smaller the increase in yearly profit and the higher the *travelersBenefit*, the larger the increase. This is due to the percentage of travelers that become customers of the MaaS provider. If the *travelersBenefit* is low, the percentage of travelers that become customer will be low, leading to a small customer base to make a profit on. On the other side, if the *travelersBenefit* is high, the customer base will be very large, but will also lead to a higher effect of the *purchaseDiscount* on the profit the MaaS provider makes. The black graph shows that for a *travelersBenefit* of 50%, which resembles a large customer base, the MaaS provider makes a significant loss if the *purchaseDiscount* is not high enough.

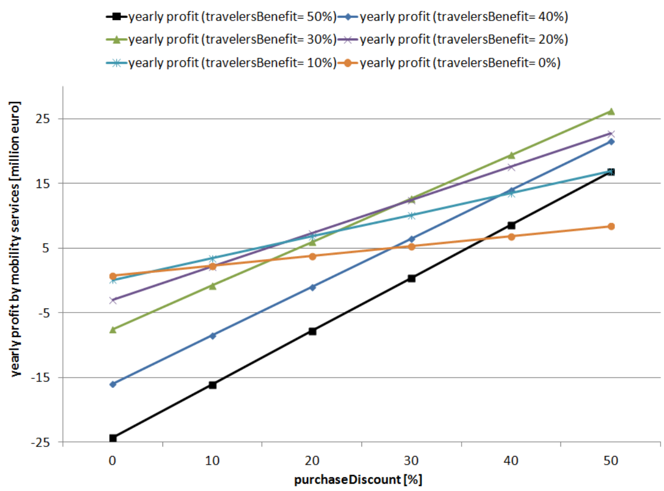

Figure 3: Yearly profit with varying purchaseDiscount and travelersBenefit

To conclude the findings that are found in Figure 3: to get the highest yearly profit, a MaaS provider has to set its *travelersBenefit* to the same percentage as the *purchaseDiscount* it receives, unless the *purchaseDiscount* is higher than 30%, then it has to keep its *travelersBenefit* to 30%.

Because the purchaseDiscount is a percentage that is given to the MaaS provider, the MaaS provider does not have a significant influence on this variable. When the MaaS provider receives no discount from its transport suppliers, the business model will never become profitable. In that case, offering information services could be the solution

C. Varying the number of sub-lists used to represent the population, as well as the number of mobility packages offered

Figure 4 shows that the percentage of travelers that become customers increases if the *nOfSublists* increases and the *nOfPackages* remains fixed. But when the number of packages offered is 6 or more, the percentage of travelers that become customers saturates when the *nOfSublists* is lower or equal to 6. If the *nOfSublists* is set to 1, the percentage of travelers that become customer stays the same no matter how many mobility packages a MaaS provider offers. This is due to the fact that only one mobility package can be constructed if *nOfSublists* is 1.

The graphs in Figure 4 where the *nOfSublists* is set to 8 or 10 follow a remarkable pattern when the *nOfPackages* is higher than 4: the graph decreases. This is due to the fact that the optimal model works with a reduced amount of mobility packages received from the reduction procedure. Because the *nOfSublists* is high, there are a lot of possible mobility packages, causing the chance that an optimal mobility package will not be included in selected packages to increase. In the optimal solution, the percentage of travelers that become customers will never decrease with increasing *nOfPackages*.

In general, the graph in Figure 4 visualizes the fact that the highest percentage of travelers that become customers can be obtained by setting the variables, *nOfSublists* and *nOfPackages* to the same value. To get the largest percentage of travelers that become customers, thus obtaining the largest market share, both the variables need to be set to 6.

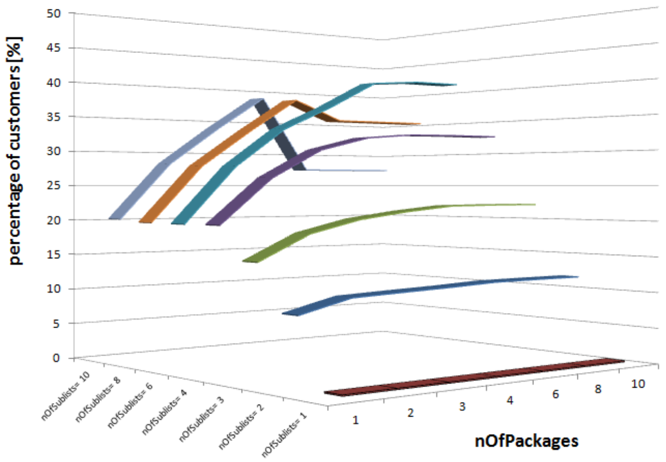

Figure 4: Percentage of travelers that become customers with varying nOfPackages and nOfSublists

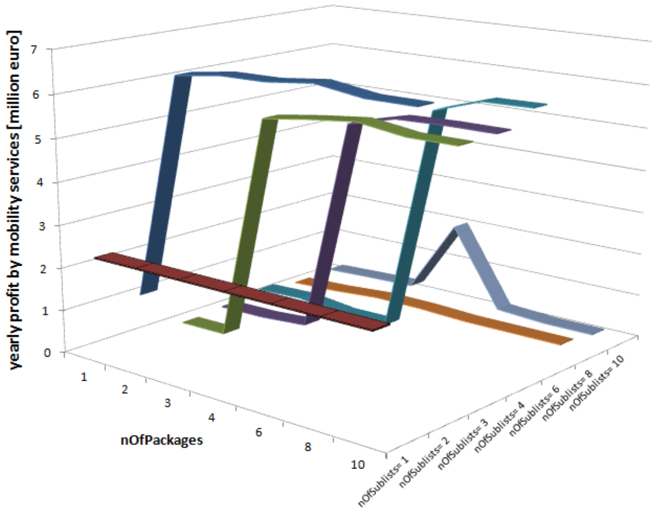

Figure 5: Yearly profit with varying nOfPackages and nOfSublists

Figure 5 shows that for almost every number of sub-lists, there comes a point where the yearly profit increases significantly. This is the point where the number of sub-lists and the number of offered packages becomes exactly the same. After this point, the yearly profit stays roughly the same for increasing number of packages offered. The big jump in the yearly profit is caused by the fact that the mobility package that is left out when the *nOfPackages* is equal to the (*nOfSublists*-1) is a package that offers a lot more kilometers than the offered packages. When this package is included by increasing the *nOfPackages,* the yearly profit will increase significantly. The highest percentage of travelers that become customers can be obtained by setting the variables, *nOfSublists* and *nOfPackages* to the same value, more specifically to 6.

V. Conclusions & Future work

Mobility-as-a-Service (MaaS) represents the shift from a system focusing purely on the transportation itself to a multi-modal system that focuses heavily on the end-users and a better service level, and hence ensures convenient switching between different transportation modes. A MaaS provider offers mobility packages that combine options from different transport providers into a single, yet multi-modal, mobility service. Customers of a MaaS provider also generate a significant amount of data about their mobility behavior. Valuable information, like travel patterns, can be extracted out of this data. Because of this reason the value of MaaS goes beyond offering smooth mobility services to customers, it also allows providing information services. The challenge of this paper was to construct a business model for a MaaS provider in the current mobility ecosystem. A MaaS ecosystem consists of a range of different stakeholders, each of whom play an important role in this concept. The Osterwalder Canvas was used to visualize the business model. Afterwards, the costs of a MaaS provider were estimated for an ecosystem that would be located in Flanders, Belgium. Obviously, to compensate the cost that a MaaS provider has, revenue needs to be generated. This revenue originates from both the mobility and information services offered.

These estimations were used in a Java-based model to be able to simulate the MaaS ecosystem. The goal of this simulation model was to get a clear view on the degree of importance of the two services that a MaaS provider can offer.

The business case was evaluated by using the yearly profit of the MaaS provider originating from the mobility services and the percentage of travelers that become customers as the performance indicators during the different tests. The purpose of the tests was to find out which parameters had a significant impact on the business model.

As a result of these tests, the exact influence of some parameters was found. To conclude this paper, the knowledge that was acquired was used to construct some recommendations. These recommendations can be used when a MaaS provider wants to install the MaaS concept in a particular region:

- The MaaS provider has to negotiate a deal with the individual transport providers that gives the best possible purchase discount. The higher the discount, the higher the yearly profit will be, because the yearly profit increases linearly with an increasing purchase discount.
- It is important to consider both the short and long-term horizon. First try to increase your market share by increasing the discount given to the travelers. This

will have a negative effect on the yearly profit in the short-term but in the long-term a higher yearly profit will be obtained, because a higher purchase discount can be received if the market share is higher.
- In principle, when the MaaS provider gets a purchase discount of 5% or higher, it is capable of constructing a profitable business model without offering the information services. But even then, it is recommended to include the information services because they do not have a significant cost in comparison with the extra revenue they could generate.

Some aspects of this paper have to be further investigated to get a more realistic operation of a MaaS ecosystem and consequently an even more realistic business model. Potential optimizations or additions to the implementation model are the following:

- Include other transport modes, for example taxi.
- Try to get to know the exact *purchaseDiscount* that the MaaS provider would receive to use in the model, which makes the model more realistic.
- Instead of focusing the implementation model on a fixed transport provider per transport mode, other transport providers could be included to compare the different scenarios to each other, and even construct business cases for other countries.
- Work with real persons instead of generating them.
- To make the model even more realistic, the process that assigns a preference to a person and the process that assigns a travel to a transport mode should be further developed.
- The algorithm that simulates the decision process that decides whether a traveler will buy a mobility package, can be improved by asking travelers to fill in a questionnaire.

When installing a MaaS concept, a lot of challenges will be encountered. How exactly these challenges can be solved needs to be further investigated, but this paper definitely identified some:

- The most obvious challenge that needs to be further investigated is how the cooperation between the different transport providers and the MaaS provider will evolve.
- A MaaS provider makes use of an integrated payment system. How such a system is implemented with all the transport suppliers of a MaaS provider needs to be further investigated.
- What the exact impact will be on the business models of the separate transport providers, is not yet determined. It is possible that the transport providers have to move away from a business-to-consumer model to a model that is focused on supplying transport resources through a MaaS provider.
- The big challenge about the data aspect of Maas will be the privacy of the customers.
- To get the full effect of the MaaS concept, the mobility infrastructure has to be well developed. Are the governments willing to invest in such infrastructures?

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List of abbreviations and symbols

MaaS	Mobility-as-a-Service
GPS	Global positioning system
NMBS	Nationale Maatschappij der Belgische Spoorwegen
FAC	Fully allocated cost
IOT	Internet of Things
JAVA	Object-oriented, class-based computer programming language
LP	Linear Programming
Gurobi	Optimization solver for linear programming, mixed integer linear programming, etc.
CPU	Central Processing Unit

List of variables used in the implementation model

nOfPersons	Size of the population that is being tested
nOfPackages	Number of mobility packages that are offered to the travelers
nOfSublists	Number of sub-lists used to represent the travelling needs of the whole population for a single transport mode
percentageAboveOfferedKilometers	The maximum percentage of needed kilometers a person is willing to buy from the separate transport providers on top of the mobility package of the MaaS provider
nOfMatches	Number of travelers that decide to become a actual customer of the MaaS provider
travelersBenefit	The discount a travelers gets from the MaaS provider on the original price of the transport services offered by the separate transport providers
purchaseDiscount	The discount that a MaaS provider gets from different transport suppliers
percentageCostDifferenceAllowed	The maximum percentage of the cost that a traveler is willing to pay extra for the sake of comfort and efficiency
differenceCost	Difference between the traveling needs of a traveler and a mobility package. This difference is used as weights in a cost function.

1 Introduction

The number of vehicles in Belgium increased with 16.8% from 2006 to 2016 [1]. It is plausible to say that the number of vehicles will only increase further in the coming years and that, indirectly, the congestion level in Belgium will increase accordingly. The evening traffic jams in 2016 were on average 16 kilometers longer than in 2015 [2]. This increase causes that the amount of time employees waste in traffic increases, the emission rises, roads fray through faster, etc. The average amount of travels per day is 2.74, 69.62 percent of those travels happen by car [3]. Every action taken to lower the travels made by car will improve the smoothness of every travel remarkably. To prevent the increase of all these negative statistics, the mobility sector needs to take a different path. A future direction the mobility sector can take is to move away from individual transport modes towards a multi-modal system. Mobility-as-a-Service (MaaS) is such a system that will ensure convenient switching between different transportation modes, including bus, train, bicycle, car and others. An integrated payment system will be used that makes the payment easier for the customers and as a side-benefit simplifies the collection of travelling data. Due to the digital evolution, the amount of available data grows exponentially. The mobility problems (traffic jams, environmental concerns, etc.) could benefit immensely from the travel information gathered about the customers of a MaaS provider. Travel information can be derived from the collected data and used to convince drivers to take public transport and to reduce roadway and parking congestion. How to switch from the regular mobility environment to a MaaS ecosystem and its most likely consequences, will be one of the topics of this master dissertation.

Existing research about MaaS mainly focuses on explaining MaaS on a conceptual level. The transport from a human end-user perspective, the travel instead of transportation, is discussed in detail by Giesecke et al. [4]. Alongside the nature of travel also the sustainability of MaaS is being addressed. Finger et al. explain the concept MaaS and what it could develop into in the context of congestion problems and changing mobility patterns [5]. It also discusses the switch from the regulation of transport as a sector to the regulation of transport as a service. Benefits of MaaS like door-to-door journey and simple and easy customer experience are described in [6]. An overview of a possible platform's architecture is given by [7] together with an explanation about how to bring mobility service supply and demand together in a common marketplace. In [8], an analysis is made about the evolution that needs to happen towards multi-modal mobility providers. Data collection in the transport industry is nothing new but, until recently, the data sources were not connected. Transport providers could determine how many people made use of their services on any given day, but did not know anything about the individual rider. The previous facts and the evolution of payment systems are discussed in detail in [9]. The focus of all the previous papers and this master dissertation is different, this master dissertation focuses especially on the business model of a MaaS provider instead of the concept MaaS. Not only which stakeholders will be part of a MaaS ecosystem are described but also how they collaborate with each other and what their influence will be on the business model of a Maas provider. Another question that is asked is "What are the parameters that have the most impact on the business model and what will this impact exactly be?". An additional dissimilarity is that the focus not only lays on the mobility services but also on the information services offered. What the impact of those information services will be on the overall business model is an important question.

Some papers focus on a specific region where MaaS is or would be implemented. [5] clarifies the MaaS concept in its practical dimension for the city Helsinki. The transformation towards MaaS in South Tyrol is explained in [10]. More specifically the challenges and opportunities for a deployment of MaaS in South Tyrol are discussed. They even evolve a web application that currently shows the real-time positions of the urban buses in the touristic town of Merano to a one-stop-shop multi-modal platform presenting real-time information. The different opportunities MaaS offers the United Kingdom are described in [11]. This master dissertation constructs a business model for a MaaS providers that operates in Flanders, Belgium. The business model is first explained in general and then applied to the real-life case of Flanders.

1.1 What is Mobility-as-a-Service?

The mindset of the younger generation about mobility is changing. Instead of owning a car, they would like to buy services to travel from a specific starting point to a destination. In addition to this, new transportation modes like bicycle and car sharing are growing steadily. Because of these changes, the focus could or should shift from a system focusing purely on the transportation itself to a system that focuses heavily on the end-users and a better service level [6]. That is exactly what the concept MaaS is about. A MaaS provider offers mobility packages and moves away from individual transport modes. Customers can buy mobility packages according to their mobility needs. A step further would be to sell pay-as-you-go packages where the travelers just pay for the service used while traveling. All these packages combine options from different transport providers into a single mobility service, removing the hassle of planning and paying all the different transport providers separately.

Customers of a MaaS provider also generate a significant amount of data about their mobility behavior. Valuable information, like travel patterns, can be extracted out of this data. The difference between the information gathered by a MaaS provider and a regular transport provider is situated in the scope of the information. Regular transport providers only collect information about the usage of that particular transport mode by a specific customer. This hence does not tell anything about the general traveling behavior of that customer. It goes without saying that general traveling behavior has much more value. Institutions such as public authorities and transport providers are interested in this kind of information and might be willing to pay for it. It is clear now that the value of MaaS goes beyond offering smooth mobility services to customers, it also allows providing information services, targeting longer horizons and allowing to identify trends that can be used for strategic decision making. These services include information towards the customer about optimal routes on different times, information about the occupation level of all transport modes, but also important information for the transport providers and authorities for longer-term planning purposes.

A MaaS provider works together with all other stakeholders. The first one, the travelers, depend on the MaaS provider to satisfy their mobility needs. Because a MaaS provider cannot compose a mobility package without the resources of the transport providers, they are hence the second stakeholder group. The most important stakeholder, the MaaS provider itself, also depends on the travelers to collect their data. Last but not least, the data-interested institutions that are elaborately described in Section 2.1, buy the travel information that is sold by the MaaS provider.

1.1.1 Challenges of Mobility-as-a-Service

The biggest challenge in our mobility behavior now is to change the mindset of the travelers. At this moment 69.62% of all the travels are made by car in Flanders [3]. The following challenges play a big role in the behavioral change of the travelers, they stimulate the travelers to choose other transport modes.

First, when installing the MaaS concept in a region or country, the infrastructure has to be well developed. If the goal is to change the mobility or to shift from specific transport methods to other, more environmentally friendly methods, the infrastructure should be adapted accordingly. For instance, a well-developed cycling road infrastructure will give the travelers a very competitive alternative to cars to move quickly from a starting point to an end point for short-distances trips [10].

Second, an integrated payment system would improve the mobility enormously. In Belgium, the MOBIB card is on the rise. The goal of the MOBIB card is to make the day-to-day transport of the traveler easier. Thanks to its contactless technology, this smart card provides easy access to a combination of public transport providers [12]. To install such an integrated system, all the transport providers have to agree to install such a payment system. Mobile payments is another step that can be taken.

In the long run, business models of the transport providers may be forced to change drastically. Transport providers may need to move away from a business-to-consumer model to a model that is focused on supplying transport resources to a MaaS provider instead of directly to the end customer [11]. This change can either be positive or negative for the transport providers. When travelers choose for car-sharing as their frequently used transportation mode, the market share of public transportation providers will decrease, this will ultimately have a negative impact on their employees. How to cope with the uncertainty about the outcome of installing MaaS will be a big challenge.

Fourth, as more pieces of transportation systems are integrated and new data sources, like car sensors, cameras, GPS and geo-location technology become available, more data will be collected [9]. A challenge is to filter out the useful data and extract travel behavior/patterns out of that data. The big challenge about the data aspect of Maas will be the privacy of the customers. The customer will not approve to make their personal information publicly. A privacy policy that works for both the MaaS provider and the customers will be a requirement [5].

Last but not least a MaaS provider will encounter some challenges to create a valuable business model. What is the price that a MaaS provider will have to pay to the transport providers to use their transportation services? If a MaaS provider has a big market, economies of scale will play an important role, if this is not the case, it will only be more difficult to make a profit. The following factors should be taken into account when analyzing economic feasibility of MaaS in a specific region: population density, existing competition, availability of open data, the legal and regulatory framework and collaboration between the important stakeholders [4]. Another business challenge will be to find a way were both the MaaS provider as the separate transport providers make a profit. A balance needs to be found to make sure that all players keep growing, maintain quality and can improve their operations [13].

1.1.2 Benefits of Mobility-as-a-Service

If a traveler chooses to become a customer of a MaaS provider, he or she should save money, time and/or effort. Those are not the only benefits a traveler gets, perhaps the most important one is the flexible and on-demand mobility packages that provide a viable alternative to owning a private car. MaaS offers freedom of choice for the travelers, they can combine public transport and private mobility services however they want.

Because MaaS is a multi-modal system, a MaaS provider has the opportunity to influence the decisions made by a customer about the transport mode to use for certain travels. The decision can be influenced by the price, if one option is significantly cheaper the traveler will reconsider its decision. Another way to influence the decision is by using a point system, the traveler earns points by choosing an e.g. more environmentally friendly transport mode. Later on these points can be used to purchase mobility packages. A private car is parked and thus is idle around 96% of the time [6]. Think about all the money that can be saved if travelers are tempted to take public transport, bicycle or car sharing instead of a private car. A direct consequence is that the congestion level and the pollution will decrease remarkably. 45.77% of the emission level in Belgium is caused by cars [14]. It is clear that the opportunity to influence the decision-making process of the travelers is an immense benefit of MaaS.

As already mentioned the impact of MaaS on the transport providers is not known in advance. It can go both ways with the number of journeys made with a private car, this amount can increase or decrease [11]. What is expected is that the travelers will shift from traveling with a private car to traveling with other transport modes. Which alternative transport mode gains most new customers, is unknown. When car-sharing is chosen to be the primary alternative for a private car, only car-sharing companies will benefit drastically from MaaS. It really depends on what the customers will choose.

When MaaS is installed, the travelers will only be customers of one transport provider, a MaaS provider, the data collected by that transport provider has significantly more value because the information hidden in the data says something about the global travel pattern of that customer. Data collected by transport providers like NMBS or DE LIJN can only collect information about the traveling behavior using that particular transport mode. Obviously, a global image about the traveling behavior has more value. This information can benefit the wellbeing of all travelers. Now the traffic on motorways as well as the public transportation traffic during peak hours is remarkably higher than on the other moments during the day [15]. The information about the traveling behavior can be used to adjust road maps and the number of transportation services that are offered at places and times that are overcrowded. These modifications will increase the chance of a smooth travel.

1.2 Goals of this thesis

As seen in the previous sections, a MaaS provider offers mobility and information services. The degree of importance of those two services is researched in this master dissertation. Therefore, the goal of this master dissertation is to find an answer to the following research question: "Is offering mobility packages enough to create a valuable business model for a MaaS provider? Are information services highly necessary to create an economically viable business model?".

The thesis starts with gaining insight into designing business models. Two different business models were constructed and afterwards the most realistic design was chosen to develop in detail in this master dissertation. What the relations will be between the different stakeholders was decided when researching the possible business models. A representation of the chosen business model and an extensive elaboration about this model can be found in Chapter 2.

The next step that is taken in the research process is allocating all the costs that a MaaS provider encounters. Therefore, some cost models from other industries like the telecommunication industry, were studied. When all the costs that a MaaS provider encounters were found, they were divided into different categories like, direct costs, shared costs and common costs. Finally, the costs in every category were allocated to the process, products or services that caused them. Cost allocation is needed to provide enough information to make business decisions in both the long and short run. It is also an important planning tool for increasing profits and reducing costs. All the different costs that a MaaS provider experiences and how to allocate them is discussed in Chapter 3.

Now that the model is fully developed theoretically, all the knowledge is available to start and implement the model. It starts with researching the different user profiles in the population. Because the influence of the different user profiles translates in the type of mobility packages that a MaaS provider has to offer to the travelers to try to convince them to become customers. The whole point of MaaS is that a MaaS provider can offer higher flexibility to the customers but the customers have to benefit from it in terms of money, time and effort otherwise they would just buy these mobility services separately. The constructed mobility packages are offered to the population to see who will become a customer. How these steps are implemented into a model can be found in Chapter 4.

Finally, the results of the model are analyzed, this analysis is discussed in Chapter 5. A scenario analysis is applied to the different assumptions taken in the model. The impact of the most important parameters is discussed. After the analysis, a conclusion is formulated in Chapter 6.

2

Business models for a MaaS provider

In this section, all the building blocks of the business model are described in detail. How to construct a business model was researched through business models from other industries and from transport providers, such as a car-sharing company [16]. Two possible Mobility-as-a-Service (MaaS) ecosystems were devised: the interaction between the stakeholders are different in those two MaaS ecosystems. The first one consists of a MaaS provider who owns private cars and bikes that are used by their customers. Other transport modes like bus and train are not owned by the MaaS provider, instead resources of external transport providers are bought, to be able to include bus and train kilometers in the mobility packages. The second possible ecosystem is one where all the resources are bought externally. Hence, the MaaS provider is a kind of middleman. Finally, the decision was made to further investigate the second possible MaaS ecosystem. How the different stakeholders of this MaaS ecosystem interact with each other is thoroughly described in the next sections. The business model canvas of Alexander Osterwalder is used to clearly visualize this business model [17]. Taking into account that MaaS offers both mobility and information services, two business model canvases are constructed.

2.1 Stakeholders of Mobility-as-a-Service

A MaaS ecosystem consist of a range of different stakeholders, each of whom play an important role. The stakeholders depend on each other to be able to function properly. The MaaS provider, the travelers, the different transport providers and the data-interested institutions form the main stakeholders of a MaaS ecosystem. How these stakeholders interact with each other is visualized in the value network of Figure 2.1 [18]. A value network is a business analysis perspective that illustrates the social and technical resources exchanged between the different nodes of the network. The nodes in Figure 2.1 represent the stakeholders of a MaaS ecosystem. This network enlists more than just transactions of goods, services and revenue. Another currency used is the knowledge value.

The transactions that take place in a MaaS ecosystem are illustrated in Figure 2.1. For example, a MaaS provider buys transportation services from the transport providers and the transport providers buy knowledge, in the form of traveling patterns, from the MaaS provider.

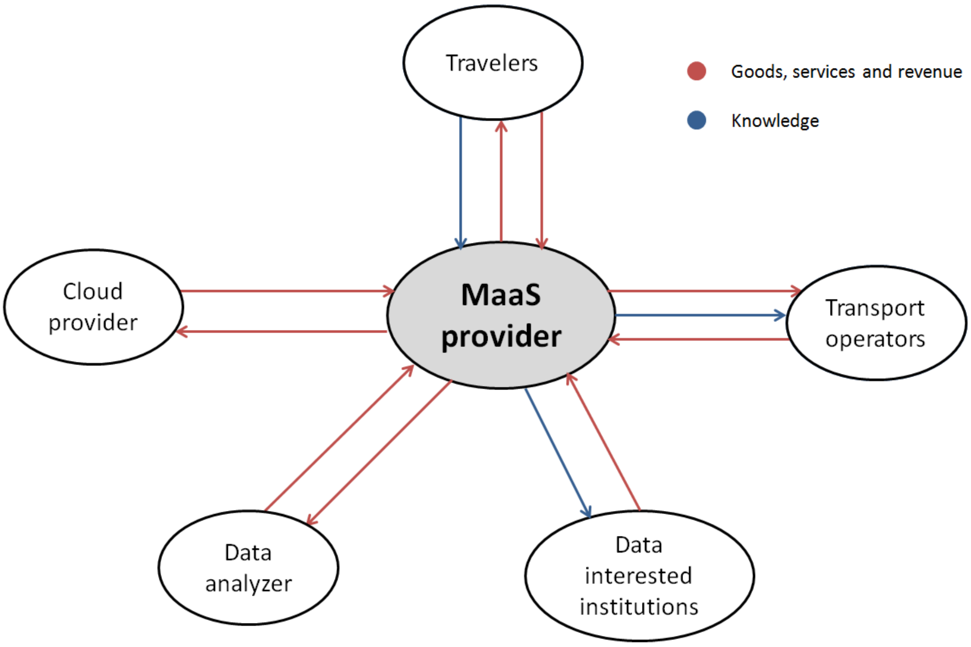

Figure 2.1: Value network of Mobility-as-a-Service

MaaS provider

A MaaS provider works together with all the other stakeholders. Different kinds of mobility packages will be created by the MaaS provider to make sure that as many travelers as possible can satisfy their needs using one of the offered packages. For example, a mobility package targeted at students has unlimited access to public buses and bike-sharing, a hundred kilometers a week of train traveling and thirty kilometers of car-sharing a week. The travelers and the MaaS provider are not only linked to each other through the mobility aspect but also because of the information aspect of MaaS. Traveling data about the traveler is collected by the MaaS provider by using an integrated payment system together with an application that stores location data of the traveler.

To be able to use the services of the transport providers, a MaaS provider needs to conclude a contract with those providers. A specific price, mostly per distance or time unit, is negotiated with those providers to pay the amount of transportation resources used in the composed mobility packages. The information service also plays a role between these two stakeholders. The transport providers could benefit a lot from the traveling patterns that are extracted out of the raw data collected by a MaaS provider. Because of that reason, there is a great chance that the transport providers are willing to pay a price for the information offered by the MaaS provider.

The link between the MaaS provider and the other interested institutions is solely based on the information aspect of MaaS. Governments, for example, can be willing to pay a price for the information so they can adjust their roadmaps, road taxes, etc.

Besides the stakeholders mentioned above there are some other companies that a MaaS provider works with to be able to function properly. A cloud provider is one of them, it is quite clear that the amount of data that is collected will be enormous, so the MaaS provider works together with another company to store all this raw data. Analyzing the data is also done by a third party, this is a very complex task because a big part of the raw data is not usable. On top of that the information still has to be subtracted out of the residuary data. The relation between such a company and the MaaS provider is beyond the scope of this master dissertation. Two other companies that work for the MaaS provider are the developer and installer of an integrated payment system and last but not least the developer of the software (application, website) used by a MaaS provider.

Travelers

As mentioned above, the travelers are looking to buy mobility services, from the transport providers separately or from a MaaS provider that offers an integrated mobility package. Transportation methods that can be included in the package are a shared bike, bus, train and shared car. It is more advantageous for the traveler to buy a package, if there is a package that satisfies all his traveling needs, than to buy all the services separately. Instead of paying for every transportation method with a different system, MaaS will implement a single payment system that can be used for all the transportation methods. Because of this single payment system, the MaaS provider knows exactly what kind of transportation methods each customer uses. A customer can be rewarded with some points if he or she chooses to go by bike, foot, bus or train instead of by car, because this is more environmentally friendly. These points can give the customer some discount on their package in the next month. The transportation behavior of the customers can be changed over time due to these kinds of measures, this will benefit the environment.

Transport providers

The transport providers sell their transportation services to a MaaS provider instead of the travelers. In return for their transportation services they receive a fee from the MaaS provider. The traveling information gathered by a MaaS provider is offered to the transport providers. Transport methods like the bus, train or bike-sharing are more environmentally friendly than the car. These means of transport can be stimulated by the government and the MaaS provider by giving points to customers who frequently use these transport methods. These points can be used with the customer's next purchase.

The first transport provider that a MaaS provider works with is a bike-sharing company like Velo Antwerp. Bike-sharing basically is taking a bike at your starting point, travel to your destination point and drop off the bike near that point. This is a fast and easy way of traveling for short trips.

The public transportation companies with whom a MaaS provider works with are a bus and train company. An example of a bus company in Flanders, Belgium, is De Lijn. NMBS is an example of a well-known train company in Belgium.

Last but not least the MaaS provider also collaborates with a car-sharing company to offer some amount of travel kilometer by car in a number of mobility packages. An example of a car-sharing company is Cambio. A big advantage of using a shared car over a private car is that the shared car is more efficiently used because a private car stands still 96% of the time according to [6]. Not all car-sharing companies have the same service mode. Some companies choose for round trip car-sharing, others for point-to-point station based car-sharing or free-floating car-sharing [16]. Point-to-point station based car-sharing means that the starting point and destination point of the car is at a known and private place of the car-sharing company. Free-floating car-sharing gives the customer more freedom because he or she can park the car wherever they want. This difference will play a role in the decision of a MaaS provider to which car-sharing company it will collaborate with.

Data-interested institutions

The link between the MaaS provider and the data-interested institutions is obvious. Data-interested institutions pay for the traveling information extracted out of the raw data that a MaaS provider collects from their customers. Examples are the transport providers itself and public authorities. The transport providers can use this information to adjust their transport schedules. For public authorities, this information is useful to adjust their roadmaps or update their mobility plans like the one in Ghent, Belgium.

2.2 Osterwalder Canvas for mobility services

This business model canvas is a visual chart that illustrates the business model of a company or organization, which, according to Osterwalder, describes the rationale of “how an organization creates, delivers and secures its value” [17]. The business model canvas consists of nine different building blocks. What these building blocks represent in the mobility aspect of a MaaS ecosystem, is described below. Figure 2.2 shows a visual of the business model canvas by Osterwalder for the mobility services offered by a MaaS provider.

Key partners

To be able to offer their mobility services to the customers, a MaaS provider needs the different transport providers as partners. Another partner of a MaaS provider is the cloud provider. The payment system used by a MaaS provider is constructed by a third party like Xerox. A Maas provider also needs an extern company that develops and maintains the software.

Key activities

Bundling the different transportation methods into one attractive mobility packages is the key activity of a MaaS provider for offering mobility services.

Key resources

The key resources of a MaaS provider according to their mobility services are the transportation services bought from the different transportation providers. Without these transportation services the mobility packages of a MaaS provider would have no value. An integrated payment system that facilitates payments of the customers is another necessary resource of a MaaS provider. Last but not least the last resource is the cloud to store all the mobility data in.

Value proposition

A combination of products and services can together form the value proposition of a company. In the case of a MaaS provider the value proposition only consists out of services. The service offered for this business model canvas is a mobility service, more specifically the mobility packages.

Customer relationships

This building block describes the type of relationship a MaaS provider establishes with its customers. A MaaS provider wants to be available 24/7 for its customers to solve their problems as fast as possible. The MaaS provider can be seen as an intermediary between the travelers and the separate transport providers.

Channels

The communication between a MaaS provider and its customers happens through a website and mobile application.

Customer segment

The customers of a MaaS provider are travelers that have a specific travel demand and want to fulfill their demand by buying a mobility package from a MaaS provider.

Cost structure

A Maas provider has multiple costs through offering mobility services to its customers. The costs are relative to their key partners. A first cost is the service used from the cloud provider. The payment system also forms a cost for a MaaS provider. The website and mobile application used to communicate with its customers, needs to be developed and maintained. Last but not least, the transport services used from the different transport providers should be paid for.

Revenue streams

A MaaS provider has only one revenue stream that originates from its mobility services. More specifically, the travelers that pay for their mobility packages.

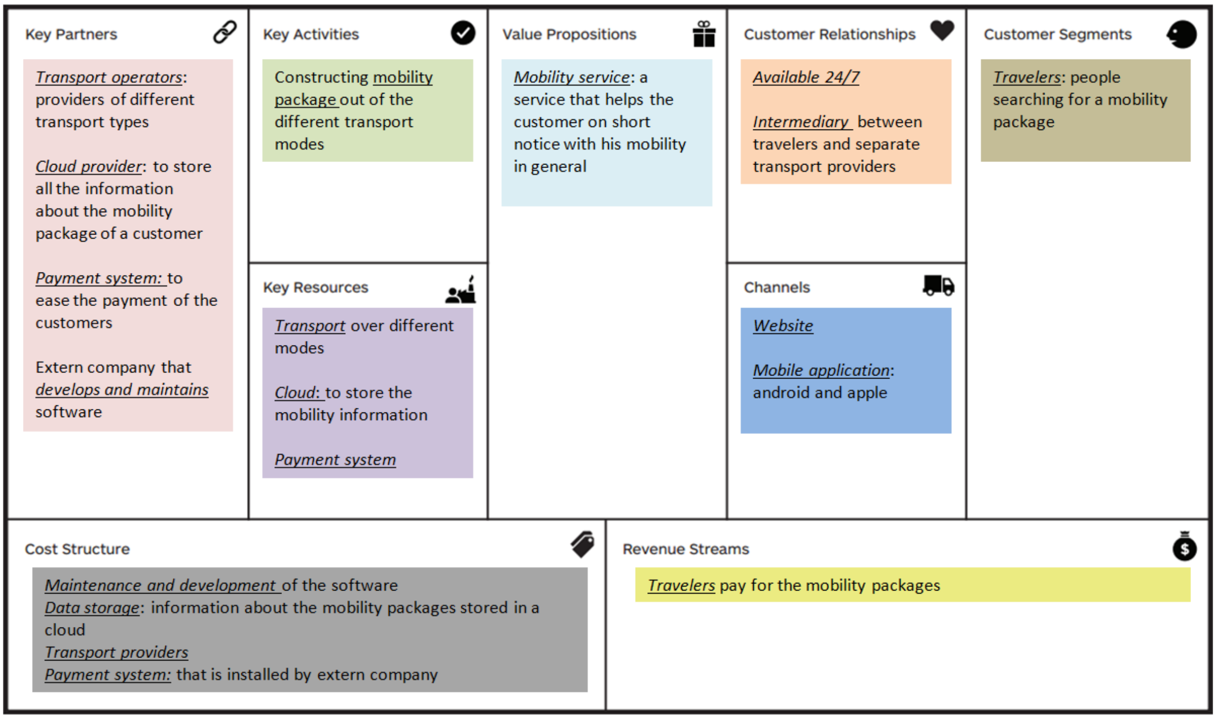

Figure 2.2: The Osterwalder business model canvas for the mobility services offered by a MaaS provider

2.3 Osterwalder Canvas for information services

In this section, the building blocks of the business model canvas for the information services offered by a MaaS provider are discussed. The visualization of this business model can be found in Figure 2.3.

Key partners

A MaaS provider makes use of a couple of different resources, the key partners of a MaaS provider are the ones that offer the key resources. More specifically, a cloud provider to store the collected data and a data analyzer to retrieve the information out of the raw data.

Key activities

Collecting data via their integrated payment system and its mobile application is the key activity of a MaaS provider for offering information services.

Key resources

A MaaS provider uses the resources of a cloud provider to be able to store all raw data gathered about the travelers. The third party that analyzes that raw data and extracts the valuable information out of it also sell its services to a MaaS provider. The data is collected by both the integrated payment system and the mobile application, thus these two systems are also key resources of a MaaS provider.

Value proposition

The information is the value proposition of a MaaS provider. This information gives an insight in the travel behavior of the different customers, which can have a lot of knowledge for the different data-interested institutions. Public authorities can use this information to adjust their current road maps or update its mobility plan. The transformation providers can fine tune their travel schemes with the obtained information.

Customer relationships

The customer relationship is the same as for the mobility services.

Channels

Communication between a MaaS provider and the data-interested institutions is done via a personal contact point. A data-interested institution submits a request with his personal contact point for a specific report. Such a report can be about a specific region or based on a certain customer segment.

Customer segment

Data-interested institutions like public authorities and transport providers are customers of a MaaS provider for the information services they offer.

Cost structure

To use the resources of the key partners a MaaS provider has to pay a price, this is the cost for a MaaS provider according to their information services. The cloud provider has to be paid for its storage space that is used. A MaaS provider works together with an extern company that analyzes the raw data, this service should be paid for as well. Although the integrated payment system and the mobile application are two key resources of a MaaS provider, they do not form a cost for the information aspect of the provider.

Revenue streams

The price paid by the data-interested institutions for the travel information generates revenue for a MaaS provider.

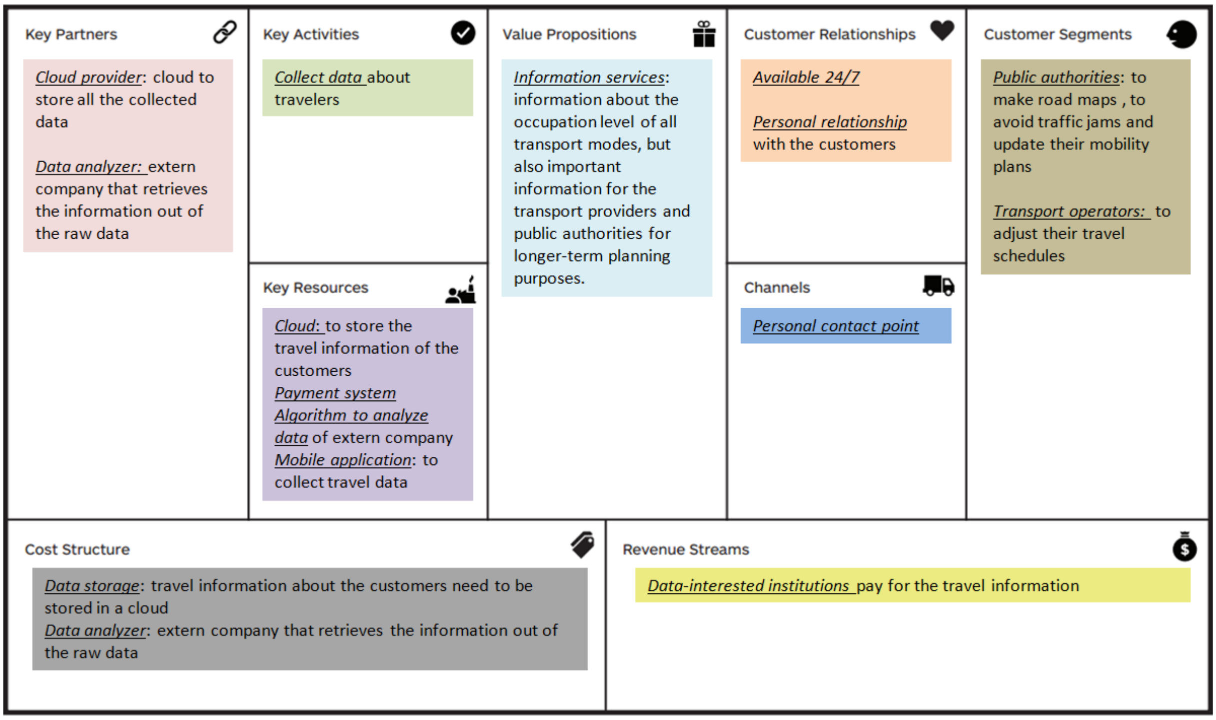

Figure 2.3: The Osterwalder business model canvas for the information services offered by a MaaS provider

2.4 Conclusion

The different stakeholders of a Maas ecosystem are the travelers, data-interested institutions, the MaaS provider, transport providers, cloud provider and the company that analyzes the raw data. The travelers and the transport providers are the main stakeholders of the mobility aspect of a MaaS provider. A MaaS provider offers mobility packages to the travelers, then the travelers decide if one of the offered packages fulfills their traveling needs. If this is the case, the traveler becomes an actual customer. Besides the mobility service, a MaaS provider also offers information services. The data-interested institutions, cloud provider and company that analyzes the data are the main stakeholders of the information aspect. An integrated payment system and mobile application are applications that are primarily used for offering mobility services to the customers, but those applications may also be used to retrieve data about the customers. For example, location data about the customer through GPS-coordinates retrieved from the mobile application. The collected data needs to be analyzed and stored, this is done by a cloud provider and company that analyzes data.

This Chapter described the relationships amongst the different stakeholders in a qualitative way. The next Chapter then quantifies the exchange of these relationships. Combining a qualitative and quantitative analysis helps to get a truthful image of the business model that is being researched in this master dissertation.

3

Business case for a MaaS provider

After a qualitative discussion about the relations amongst the different stakeholders of a Mobility-as-a-Service (MaaS) ecosystem, this Chapter will describe the quantitative analysis of those relationships. This Chapter will focus on the most important parts of the business case: the different costs and revenues encountered by the Maas provider.

3.1 Cost model for a MaaS provider

The costs that a MaaS provider encounters will originate from two different kind of services: the mobility services and the information services. Figure 2.2 and Figure 2.3 in Chapter 2 lists the different costs that a MaaS provider entails: costs with regard to the transport providers, maintenance and development cost of the applications, costs to install an integrated payment system, the cost to store the data related to both the services and finally a cost to analyze the traveling data. Finally cost allocation will be applied, the fully allocated cost (FAC) method is used [19]. This method allocates all costs to all the services. Cost allocation is needed to provide enough information to make business decisions in both the long and short term, it is also an important planning tool for increasing profits and reducing costs. How this allocation exactly happens will be discussed further in this Chapter. Before this allocation takes place, all the costs have to be subdivided into different categories. Categorizing costs is done by grouping the costs together on the basis of common characteristics like nature or source. The model that is implemented is applied on a real-life example, which shows the results from a investigation that was done to see what the exact costs would be of the different costs if a MaaS provider would operate in Flanders, Belgium.

3.1.1 Cost Categories

The costs caused by the mobility services and the information services offered are subdivided into three categories: direct costs, shared costs or common costs. The different categories and the costs corresponding to these categories are shown in Figure 3.1.

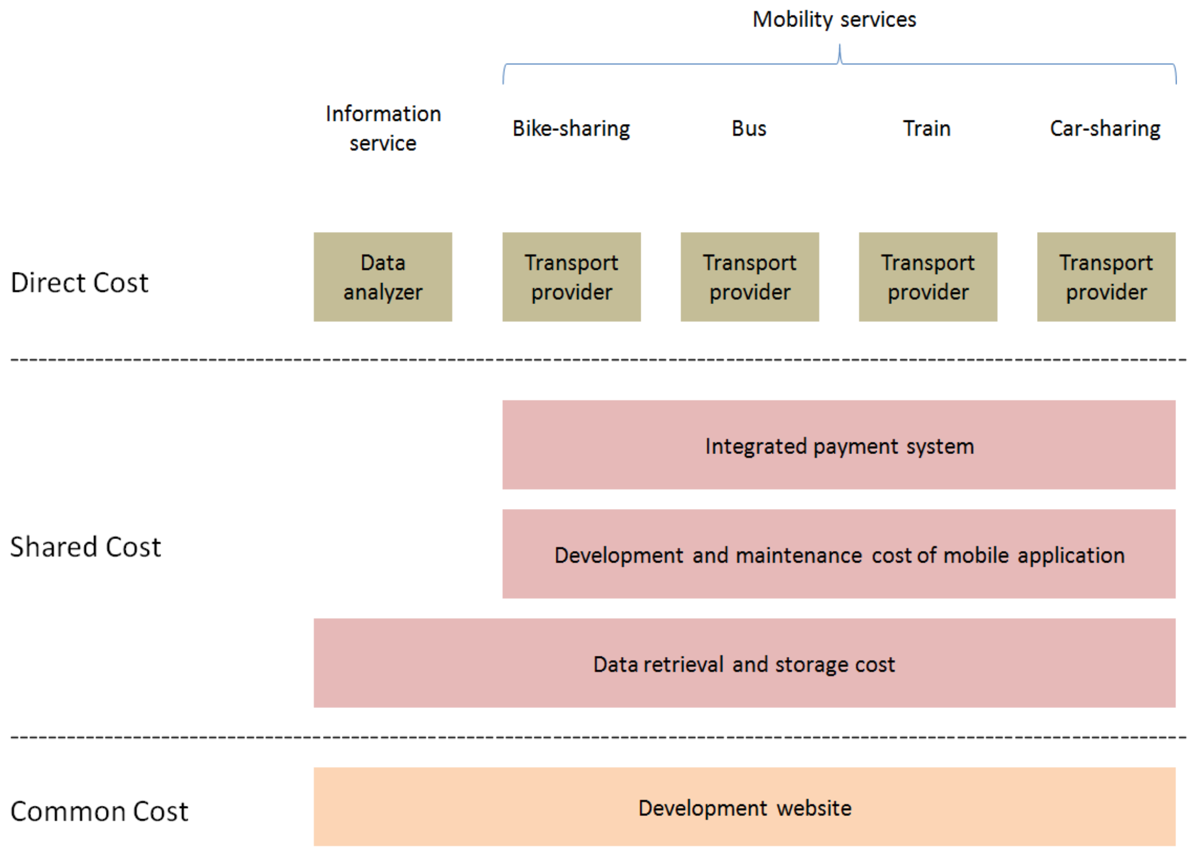

Figure 3.1: Cost categories of a MaaS provider

Direct cost

Direct costs are costs that are directly related to a product/service [19]. A direct cost of the MaaS provider is a cost that would not exist if the service was not offered. A direct cost can be further subdivided into either a fixed direct cost or a variable direct cost. This subdivision depends on how the cost reacts if the production of the products/services varies. For instance, if the cost stays the same regardless of the production level, this cost is a fixed cost. Opposite to this, the variable cost will change according to the production level of the product/service.

The cost for the transportation resources a Maas provider uses from the different transport providers, is a direct cost originating from the mobility service. This direct cost is a variable cost, because when the number of customers increase, the number of sold mobility packages will increase and so will the related cost. The total transportation cost can be divided into a cost for bike-sharing, bus transport, train transport and car-sharing. Those four costs are direct costs originating from their respective mobility service.

A Maas provider also experiences direct costs related to the information services offered to data-interested institutions. Traveling data about the customer is collected by the MaaS provider by using an integrated payment system and a mobile application. This data is raw and does not show any information yet. First, there must be some edits to the raw data before this data can be analyzed. More specifically the unusable data should be removed so the information-rich data can be analyzed. After the analysis of the data, the information can be bundled into a report and offered to potential customers. The analysis of the data is done by an external company. Despite that the information service can also benefit from the mobile application, it only is a cost for the mobility services because it was destined for those services. This leads to a direct cost for a MaaS provider. This cost is furthermore variable, obviously when the amount of data that needs to be analyzed increases, the price to do this analysis will increase accordingly. An increase in the amount of data will be the result of an increase in the number of customers.

Shared cost

Costs of resources used by a Maas provider which are mutually used by several services are called shared costs [19]. It is not possible to identify a specific service that caused the cost. The cost can either be fixed or variable for the same reasons as explained above.

Communication between a MaaS provider and its customers happens through a mobile application. The mobile application is primarily used for the mobility services offered. But an added benefit of such a application is the fact that it can be used to collect location data about the traveler through GPS coordinates. An extern company develops and maintains the mobile application, this will form a cost for the MaaS provider. This development and maintenance cost is a shared cost for all the mobility services offered by a MaaS provider. Furthermore, this cost is a fixed cost, because it will not vary if more people become customers of a MaaS provider. A fixed cost will be attached onto the development process of the mobile application and a fixed yearly cost to maintain the application.

A type of cost that is caused by both the mobility services and the information services offered is the storage and retrieval cost of all the data. That is why this cost is also a shared cost of a MaaS provider. The information service collects raw data about the travel behavior of the customers that needs to be stored. The data that needs to be stored to offer the mobility services is specific data about the mobility packages of a customer, for example the number of available kilometers the customer has left in his or her mobility package. An external company like a cloud provider is addressed to be able to store all this data. Obviously if the amount of data increases drastically, the needed storage space will increase accordingly and that will trigger the price to rise as well. The increase in the number of customers will cause the increase in amount of data. This cost is a variable cost because this cost varies according to the amount of data.

The last shared cost of a MaaS provider is the cost to install the integrated payment system. This is a shared cost for all the mobility services offered by a MaaS provider. Because the mobility services make use of the integrated payment system to ensure that the travelers have a smooth travel experience. Via this system, a MaaS provider can track accurately how many kilometers a traveler has left on his or her mobility package. An added benefit of an integrated payment system is the possibility to collect travel data of the travelers. For example, the starting points and destination points of the travels that the traveler makes. This data is needed to form a global travel image about the customer. Despite that the information service can also benefit from the integrated payment system, it only is a cost for the mobility services because it was destined for those services. Installing the integrated payment system into or onto the different transport modes will be a fixed cost because this cost will not vary with the number of customers.

Common cost

The last cost category is the common cost, this cost a cost that is not really attached to one or more services offered by the MaaS provider, but it is just a general cost for the MaaS provider [19]. There is only one common cost here and that is the cost to develop the website of the MaaS provider. This website is used to get possible customers of the mobility service or the information service to get to know the concept that a MaaS provider tries to install. An external company develops and maintains this website, it is safe to say that this is a fixed cost because the cost will not vary significantly if the number of customers increased or decreases.

3.1.2 Allocation of the different costs

Cost allocation is a process of linking the different costs to the cost objectives that caused them [20]. Often this process is accomplished by selecting cost drivers. Some costs are not important enough to be allocated individually, these are then pooled and afterwards allocated together to cost objectives using a single cost driver. The allocation of costs is done to compute income, base selling prices or to support business decision in both the short and long term. The different costs of a Maas provider are allocated according to the fully allocated cost (FAC) method [19].

First, the direct costs are allocated:

- The cost driver of the transport cost of a MaaS provider is one kilometer, this allocation is simple because this cost can be directly associated with the mobility service that caused it. For every transport mode, an number of kilometers is needed and a cost is attached to that number of kilometers.

- The second direct cost is the cost that a Maas provider has to pay to the extern company that analyzes the raw data. The travel behavior of every person can be very different, that is the reason that the cost driver cannot be the number of customers. It is furthermore very difficult to attach the number of bytes as the cost driver of this particular cost, since a lot of the collected data will be unusable, this data has to be removed first. What the exact number of useful bytes per travel will be is not known. This kind of research is not the core of this master dissertation so the choice was made to choose a single travel as the cost driver for this cost.

The allocation of the shared cost of a MaaS provider are described below:

- The storage and retrieval of data cost is a shared cost of a MaaS provider that has a single byte as cost driver. The mobility service only keeps track of the number of kilometers a customer still has available in his mobility package while the information service keeps track of every detail of the travels a customer makes. Hence this cost will be allocated to one of the two services according to an assumed percentage. For instance, 10% of the cost will be allocated to the mobility services and 90% to the information services.

- Another shared cost is the cost of installing the integrated payment system. This cost is shared between the different transport modes that are offered in a mobility package. The cost driver of this cost is the amount of systems installed. Every vehicle of the transport modes that are used must have an integrated payment system so actually the cost driver is the number of vehicles that can be used by all the customers. The total cost will be subdivided over the different transport modes by the amount of payment systems that every transport mode uses.

- The last shared cost is the cost of developing and maintaining the mobile application, this is a fixed cost. Hence this cost will be evenly allocated over all four mobility services.

Finally, there is one common cost, the cost to develop the website, which can be seen as an overhead cost. This cost will be evenly divided amongst the information and mobility services. 50% of the cost is allocated to the information services and 50% to the mobility services.

3.1.3 Real-life example

To get an idea what all these costs would be in real-life, an estimation was made of the costs for a MaaS provider that would be located in Flanders, Belgium. First, research was done to the prices of a transport provider of every transport mode that is included in the mobility packages. If the MaaS provider has a large number of customers it will need a large number of transport kilometers of the separate transport providers. For this reason, a MaaS provider can most likely benefit from economies of scale. Purchasing services in a large bulk establishes an economy of scale by allowing the cost per unit to be lower. This means that a large business can buy services with a large discount because of the purchase in bulk. All the prices mentioned below are prices independent of the economy of scale. This principle is only applied in the model that is implemented, see Chapter 4.

The prices that are estimated in this real-life example are:

- The transport price per kilometer since a MaaS provider offers transport services per kilometer. First, the real prices that the transport providers appeal to their customers are mentioned. Out of these prices, the price per kilometer can be derived.
- The cost to store, retrieve and analyze all the data.
- The cost to develop and maintain the mobile application.
- The cost of the integrated payment system.
- The final cost in this real-life example is the costs of developing a website.

Bike-sharing

The bike-sharing company Velo in Antwerp was chosen to estimate the cost that a MaaS provider would have to pay to a bike-sharing company in Flanders, Belgium. How does the concept of bike-sharing work? When you have to travel a short distance and you want to avoid traffic, a bike is the perfect solution. Instead of owning a private bike that you have to take care of, it is possible to lend a bike. You take a bike near your departure point, travel to your destination and leave the bike at a bike station near your destination point. The bikes of Velo are available every day of the year and every moment of the day. There are three ways to sign up [21], as seen in Table 3.1. The cost per usage of a bike is listed in Table 3.2.

Table 3.1: Cost to sign up with Velo Antwerp

Sign up	
Day pass	4.00 €
Week pass	10.00 €
Annual card	49.00 €

Table 3.2: Cost for a ride with Velo Antwerp

Usage/ride	
0 – 30 min	Free
30 – 60 min	+0.50 €
60 – 90 min	+ 1.00 €
90+ min	+ 5.00 €

The average speed when travelling with a bike is around 15,4 kilometers per hour [22]. Claes et al. states that the bike is used to travel up to 10 kilometers [23]. Because bike-sharing is mostly used in a city, it is safe to say that the bike is only used to travel a maximum of 40 minutes uninterrupted. This means that the traveler has to pay nothing extra for most of his travels besides the price to sign up with this company. The assumption was made that a traveler only travels more than 30 minutes once a month. This brings the yearly cost for a customer of this bike-sharing company to 55 euro (= 49 euro + 12*0.50 euro) or 1.06 euro per week. To calculate the cost per kilometer, there is assumed that the traveler travels on average 3 times a week with the bike for a distance of 5.5 kilometers. Finally, a cost of 0.065 euro (= 6.5 eurocent) per kilometer is found.

Bus (public transport)

The public transportation company used for this real-life example is De Lijn [24]. De Lijn is only active in Flanders. The customers of De Lijn have two options, they pay for a single ride or they buy a subscription for an extended period of time. A distinction for the price of the subscriptions is made between some age groups as seen in Table 3.3.

Table 3.3: Cost for a subscription of one year with De Lijn

Subscription for 1 year	
18 – 24 years	204.00 €
24 – 65 years	306.00 €
65+	52.00 €

Again, an estimation has to be made to get the cost per kilometer. Claes et al states that the bus is used to travel up to 15 kilometers [23]. If a subscription is bought we assumed that the traveler would take the bus 4 days a week, 2 times a day and that for 40 weeks in a year. This results in 320 times in one year. To estimate the cost per kilometer an average bus travel was set to 10 kilometers, this equals 3200 kilometers per year. From this, the estimated cost per kilometer is found for every age group, as shown in Table 3.4.

Table 3.4: Cost per kilometer when traveling with De Lijn

Cost per kilometer	
18 – 24 years	0.064 € (= 6.4 eurocents)
24 – 65 years	0.096 € (= 9.6 eurocents)
65+	0.016 € (= 1.6 eurocents)

A traveler will not always buy a subscription, thus to get a complete overview of the costs used in the implementation model, the cost for a single bus ticket is added. It is possible to pay per text message for a single travel all over Flanders. Such a ticket costs 2.15 euro. As mentioned above, the assumption was made that average bus travel is 10 kilometers long. This gives a cost of 0.215 euro (=21.5 eurocent) per kilometer for a single ticket.

Train

NMBS is a Belgian train company [25]. To travel with NMBS the traveler needs to buy a single ticket for one ride or a subscription for an extended period of time. Such a ticket or subscription is for a fixed trajectory. An example of a fixed trajectory is the displacement from work to home and back. To estimate the cost per kilometer to travel with NMBS, three trajectories were chosen to work with. The trajectories are: from Liedekerke to Oostende, from Oostende to Brussel Centraal and from Denderleeuw to Brussel Centraal, as seen in Table 3.5.

Table 3.5: Subscription and single-ticket prices of NMBS for three trajectories

Cost per kilometer	**Liedekerke → Oostende**	**Oostende → Brussel Centraal**	**Denderleeuw → Brussel Centraal**
Distance [kilometer]	40	115	25
One year subscription cost [euro]	1108.00	2533.00	961.00
Single-ticket cost [euro]	5.50	17.40	4.60

Once again the assumption was made that the traveler would take the train 4 days a week, 2 times a day and that for 40 weeks in a year. In total this comes down to 320 times a year. When dividing the subscription cost by the trajectory distance multiplied with 320, the cost per kilometer was obtained. After taking the average of those 3 costs the estimated subscription cost per kilometer to travel by train is 0.092 euro (= 9.2 eurocent). The single-ticket cost per kilometer is included here for the same reasons as mentioned for the transport by bus. This cost is calculated by taking the average for those three trajectories, which results in 0.158 euro (=15.8 eurocent) per kilometer.

Car-sharing

Cambio is a small car-sharing company that operates in Flanders, Belgium [26]. The car-sharing concept is relatively the same as bike-sharing, except that now the travel itself happens with a car instead of a bike. A big disadvantage of owning a private car is that most of the time the car is idle.

Because of this reason getting a subscription with a car-sharing company is an excellent alternative. The company Cambio has 5 different formulas were the customer can choose from, these are listed in Table 3.6.

Table 3.6: Cost of the different formulas of Cambio

Formulas of Cambio

Amount of km per year	Cost subscription (per month)
3000 km	113.00 €
5000 km	172.00 €
6500 km	216.00 €
8000 km	259.00 €
10 000 km	318.00 €

For each formula, the number of kilometers and the cost is known, thus the cost per kilometer can be calculated. After taking the average of these 5 different costs per kilometer a cost of 0.408 euro (= 40.8 eurocents) per kilometer is found.

Storage and retrieval of data

A cloud provider that is frequently used in Belgium is Microsoft Azure [27]. Their price calculator suggests that storing 1 terabyte of data in the cloud would cost around 70 euro per month. This cost multiplied with the amount of terabyte a Maas provider has to store each month results in the total cost to store the data. Data retrieval is fairly simple because it only consists of sending data from the sources that retrieved it to the cloud, to store it. Because of this reason, we assumed that the cost of data retrieval can be represented by 20% of the storage cost. Hence the total cost will be 84 euro (=$70 + 0.20 * 70$) per month per terabyte.

Data analyzer

“Sentiance is a data science company turning IOT sensor data into rich insights about people’s behavior and real-time context” [28]. No exact data was found about this cost. This was kept in mind throughout the simulations, if the information services were used to generate extra revenue, this cost still needs to be extracted from the profit.

Integrated payment system

The assumption was made that the price of the integrated payment system can be accessed by the transaction fee that have to be paid when paying with visa, this is around 0.85% [29].

Development and maintenance of the mobile application

The average cost to develop and maintain an application is around 270 000 dollars (±240 000 euro) [30]. We assume that an application is developed for around 1 million users. The simulation will be done with a population size smaller than 1 million. If the population size is 100 000 than the cost for the mobile application is around 27 000 dollars (±24 000 euro).

Developing a website

After using the price calculator, an estimation of the cost to develop a website was found [31]. This cost would be around 20 000 dollars (±18 000 euro). After applying the same principle as above the cost would be around 2 000 dollars (±1 800 euro) if the population size is 100 000.

3.2 Revenue model for a MaaS provider

To compensate the cost that a MaaS provider has, revenue needs to be generated. This revenue originates from both the mobility and the information services offered. How the revenue is exactly generated per service offered is described in detail below.

3.2.1 Revenue generated by mobility services

The revenue generated by the mobility services is solely originating from the mobility packages that are sold to the travelers. The revenue generated by a single mobility package is calculated by multiplying the offered number of kilometers of each transport mode with its respective cost and the amount of customers that bought this mobility package. After summing up the revenue generated by every single mobility package, the total revenue is reached. There are two aspects about these mobility packages causing a MaaS provider to make some profit.

The first one was already mentioned above, by purchasing transport services from the separate transport providers in bulk, a MaaS provider gets some discount. This concept is called economies of scale. If a traveler would buy subscriptions or single tickets at the separate transport provider, he or she would have to pay the full cost of such a ticket. Because of the discount, a MaaS provider is able to sell the same transport service at a cheaper price. Now the MaaS provider has a choice to make. Is the received discount used to lower its prices as much as possible and thus meaning that a MaaS provider does not gain any direct profit out of the discount received, as in Figure 3.2? Or is some part of the received discount used to lower its price and the other part used to make a direct profit, as in Figure 3.3? The direct profit that the MaaS provider makes in Figure 3.3 is equal to 0,5 euro per kilometer. The MaaS provider buys services of a train company for 8.5 euro per kilometer and sells it to their customers for 9 euro per kilometer. Both the purchase discount as the travelers' benefit is according to the price per kilometer that the travelers have to pay to the separate transport companies. By setting the cost of its mobility packages as low as possible the MaaS provider will attract more customers, in the long run this can generate even more profit.

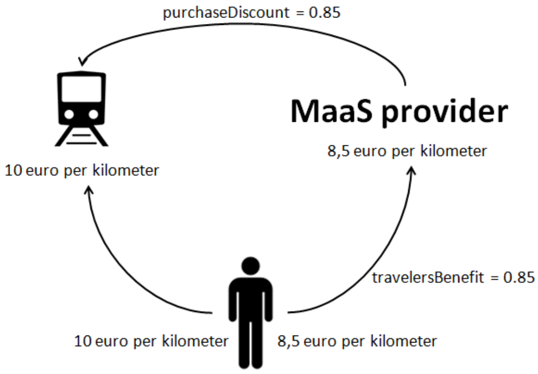

Figure 3.2: Situation were travelers benefit equals purchase discount

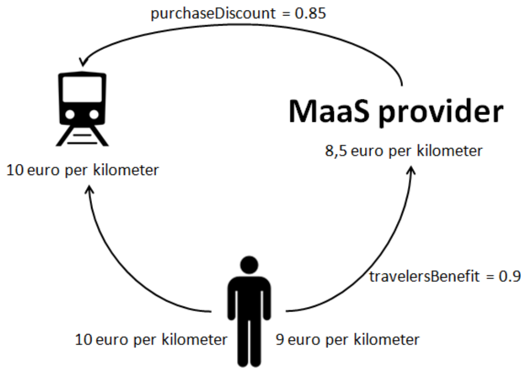

Figure 3.3: Situation were travelers benefit is less than purchase discount

The second way a Maas provider generates profit is because on average the customer will not use all the transport services in the mobility package that he or she bought. For instance, the travelling needs of a person are the ones that are listed in Table 3.7 and the number of kilometers offered in the mobility package are listed in Table 3.8. It is clear that person x does not use all the transport services offered in mobility package y. More specifically his travelling needs by bike and car are lower than the number of kilometers offered for those two transport modes. For the bike, there is a difference of 5 kilometers and for the car 50 kilometers. After multiplying those two amounts with the respective costs found in Section 3.1.3, this results in an extra profit of 20.7 euro per week for the MaaS provider.

Table 3.7: Traveling needs of person x

Travelling needs of person x

Transport mode	Amount of km needed (weekly)
Bike	20
Bus	0
Train	70
Car	250

Table 3.8: Transport services offered in package y

Mobility package y

Transport mode	Amount of km offered (weekly)
Bike	25
Bus	0
Train	70
Car	300

3.2.2 Revenue generated by information service

The revenue generated by information services is through travel reports that are sold to data-interested institutions. Some examples of data-interested institutions are: transport providers such as De Lijn and NMBS, local, regional and national authorities and cities in general. An example of a specific report is a report that is based on a single age group, employed people versus unemployed people or of a single city. For instance, if the mobility department of Ghent wants to update their mobility information they can buy a report from a Maas provider that includes all the travel behavior that took place in Ghent. An extensive report can be a report that is based on an entire country, those kinds of reports can be interesting for a government. Attaching a cost to those reports is very difficult. The cost will depend on different parameters. For example, the scope of the report will be an influential parameter when calculating the cost. How to monetize data is not the main objective of this master dissertation, thus what the exact revenue will be that is generated by the information services is not calculated.

3.3 Conclusion

This Chapter focused on a quantitative analysis of the different relationships amongst the stakeholders of a MaaS ecosystem. The costs that a MaaS provider experiences and the revenue it generates were described in detail. First, the costs were categorized as a direct cost, shared cost or common cost and then subdivided into the category fixed costs or variable costs. The direct variable costs of a MaaS provider are the cost that need to be paid to the separate transport providers and the cost for using the services of an extern company to analyze the data. Next to the direct cost, a Maas provider has three different shared costs, those are caused by more than one service that is offered by the MaaS provider. The development and maintenance cost of the mobile application is a shared fixed cost of the mobility services offered. A shared variable cost of both the mobility services as the information services offered is the storage and retrieval cost of the data. Installing an integrated payment system causes the third and last shared cost, this is a fixed cost for the mobility services offered. A MaaS provider also has a common cost, this is the cost to develop and maintain the website. After these costs are described and categorized they are allocated based on a specific cost driver. The different cost drivers used are per kilometer, per byte, per customer and per transport vehicle used. To get a good understanding of the different costs, a real-life example was constructed, to estimate what the actual costs would be if a MaaS provider would offer its services in Flanders, Belgium.

To compensate the costs, a company needs to generate revenue. The revenue of a MaaS provider originates from both mobility and information services offered. The revenue originating from the mobility service is created by selling mobility packages to interested travelers. A MaaS provider has some advantages over a single traveler. A Maas provider buys the transport services from the transport providers in bulk, which gives them a discount on the price per kilometer. The price per kilometer that a MaaS provider pays to the separate transport providers is based on the subscription prices, not on the price of a single ticket. On average a person will not fully make use of the capacity of his or her subscription. Meaning that not all the kilometers bought through a mobility package will be used. A MaaS provider only pays for the resources it uses, thus the difference between the number of kilometers that are offered and the amount that is used is a source of income for the MaaS provider. The revenue originating from the information services is solely generated by the travel information reports that will be sold.

Both the costs and the revenue of the MaaS provider need to be investigated in detail, before a substantiated decision can be taken about the business case. Different scenarios will be simulated to see how the costs and revenue will react, this knowledge is needed to be able to take a well-considered decision about the business case. The model developed to do these simulations with, is elaborately described in the next Chapter.

4
Simulation model and its building blocks

After analyzing the business case, a model was constructed to simulate the Mobility-as-a-Service (MaaS) ecosystem. This Chapter will describe the different building blocks of the implementation model. The implementation is done in JAVA. Four classes are used to implement all the actions that will happen by a Maas provider before offering its services to a group of travelers. How these classes interact with each other can be found in a sequence diagram, showed in Figure 4.1. A sequence diagram shows, in sequential order, all the interactions that happen between the different objects and in what order. The first class "Data" is used to generate all the data needed to simulate a traveler. A week schedule is generated that shows the traveling needs of a traveler, an example of such a week schedule can be found in Appendix 1. With this data, all travelers can be generated, this happens by linking a week schedule and its associated characteristics to a person in the class "Person". For each person, the number of needed kilometers per transport mode is being requested by the central class "Main". The central class then uses these amounts of kilometers to generate the best mobility packages in the class "MobilityPackage", meaning the packages that would attract the most customers out of the travelers generated. The visualization of a mobility package constructed by the model can be found in Appendix 2. Finally, the constructed mobility packages are offered to the travelers, thus the amount of travelers that become customer can be derived. When the customers are known, the costs and revenue can be calculated with the values found in Chapter 3. Afterwards all the facts are known to decide if this model is valuable by only offering mobility service or does a MaaS provider needs to offer information services as well.

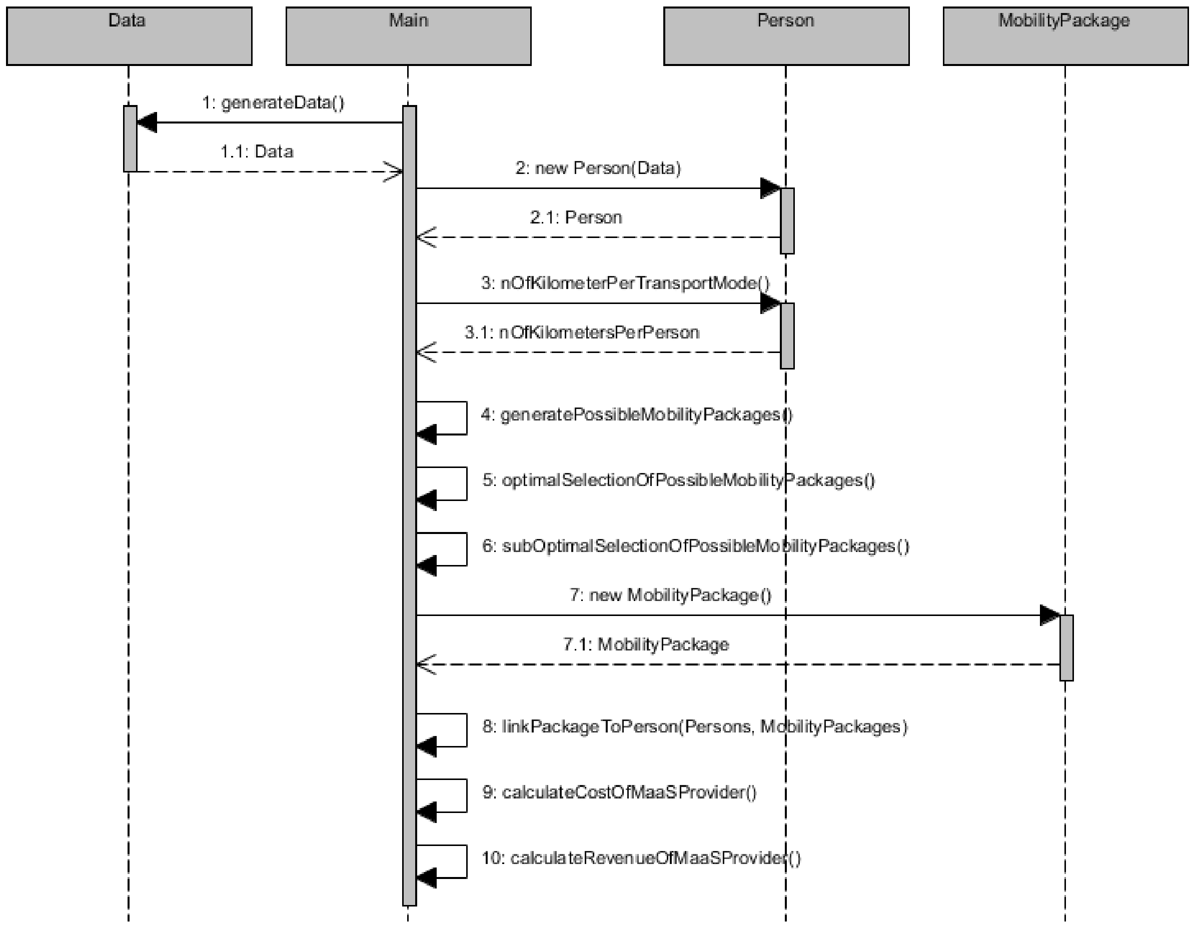

Figure 4.1: Sequence diagram of implementation model

4.1 Generate travelers

As already mentioned, the implementation starts by generating week schedules (Appendix 1) that are afterwards used to generate persons. A week schedule is generated according to some characteristics of a person (Table 4.1). Those characteristics are generated due to statistics found in literature. The statistics about the age category and the gender in every age category were found in [32]. The work status of the person is determined according to [33]. Figure 4.2 shows the exact statistics per characteristic that are used in the implementation model.

Table 4.1: The characteristics of a person used to generate a week schedule

Characteristics of person to simulate week schedule	
Age category	18 to 64 | 64 and above
Gender	Male | Female
Work status	Employed | Unemployed | Retired
Preference	Time | Money | Time and money (50/50) | Time and money (60/40) | Time and money (40/60) | Environmentally Friendly

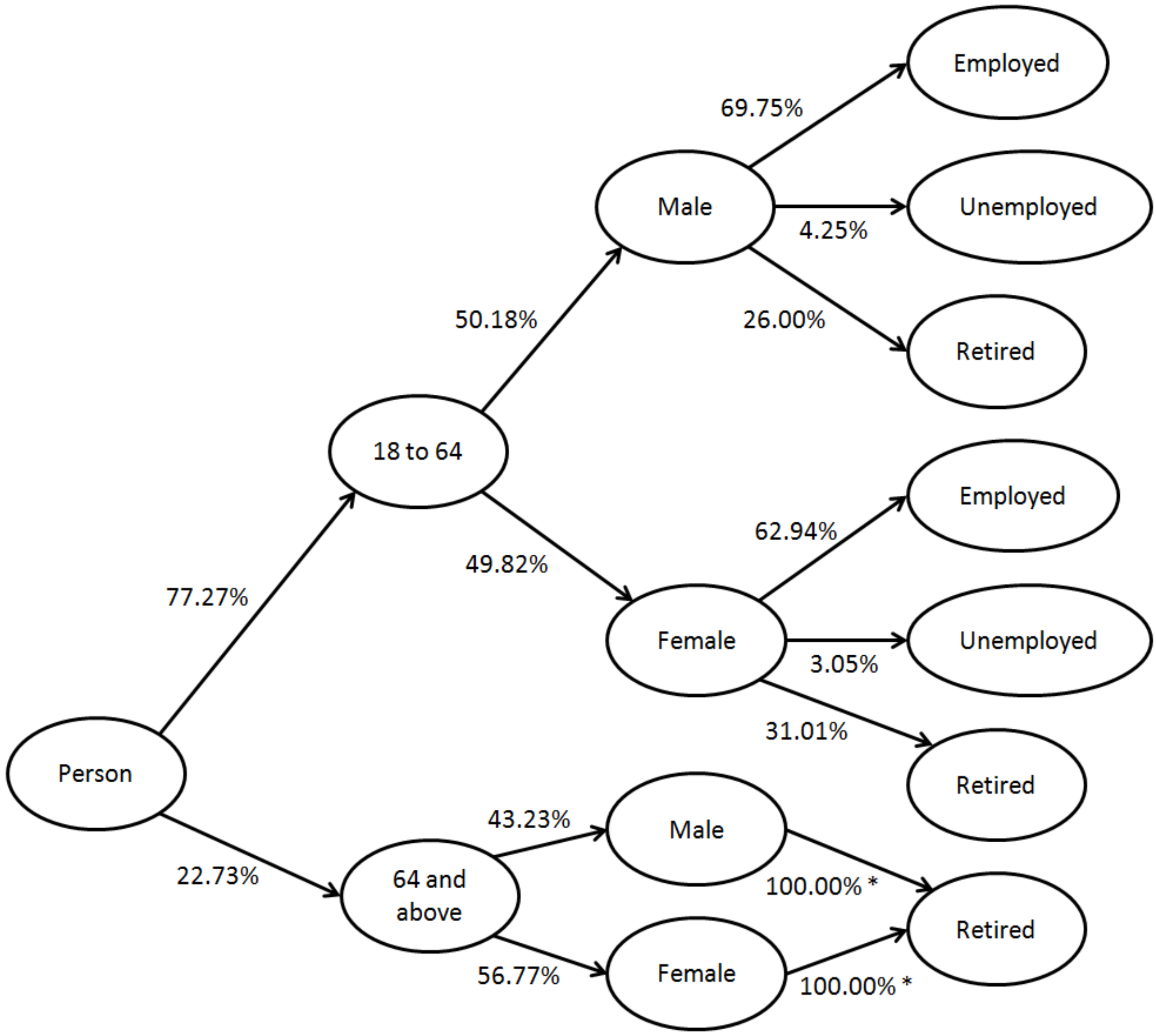

Figure 4.2: Statistics for the characteristics of a person used in the model (*: assumptions)

Women or men above 64 are assumed to be retired in this model. How to assign a preference to a person is complicated, because it is difficult to simulate how a person would choose when comparing transport modes. Two preferences used in the model are time and money. But in most cases a person will choose a cheap and fast option and not only consider the time it takes or the money it costs. There are three preferences that resemble a balance between the time it takes and the money it costs: a preference where this balance is fifty/fifty, one that leans more towards the cheapest option and one that leans more towards the fastest option. Another preference that a person can have, is to take the most environmental friendly option. To work with this last preference, the assumption was made that the order of environmental friendly transport modes from most to least is as follows: by foot, bike, bus, train and car. In this implementation model the assumption was made that all of the preferences mentioned in Table 4.1 have a chance of $\frac{1}{6}$ to be picked, this distribution is assumed to be static.

Now that the characteristics are simulated it is time to simulate the actual week schedule of the person. In the model a distinction is made between an employed person and an unemployed person according to the displacements made. On average a person has around 3 travels a day [3]. The assumption is made that an employed person travels on average 5 times a day from Monday to Friday, including a trip from work to home and back and 3 times a day in the weekends. An unemployed person travels 3 times a day on every day of the week. Hence, every person travels at least 3 times a day, when these travels will happen are based on research that was done about the displacement behavior of the people in Flanders [34]. In this report, the frequencies of a displacement starting at a specific hour were found, these are listed in Table 4.2.

Table 4.2: The frequency of a displacement starting at a specific hour in Flanders

Frequency of a displacement starting per hour interval		
Departure hour	**Weekday**	**Weekend day**
0	0,440	0,672
1	0,190	0,451
2	0,110	0,261
3	0,050	0,170
4	0,050	0,100
5	0,960	0,191
6	2,501	0,592
7	7,284	2,316
8	8,974	4,552
9	5,143	8,322
10	6,263	9,636
11	5,343	11,611
12	6,913	6,317
13	6,203	7,891
14	6,613	7,360
15	8,594	7,260
16	9,485	6,237
17	8,664	7,420
18	5,513	6,227
19	4,232	4,693
20	2,411	3,499
21	1,721	2,056
22	1,291	1,364
23	1,051	0,802

There was a small number of respondents that did not give an answer on the question asked to do this research. Hence, the numbers in the report were slightly adjusted to get the right frequencies. The employed people need to do 2 travels per day extra from Monday to Friday, both with the same distance that needs to be covered, this because the distance from home to work is the same as from work to home. The travel from home to work will happen in the interval from 06h to 09h. And the travel from work to home in the interval 15h to 19h. Now that the moments that a person starts his or her travels is determined, the only thing left is to determine the number of kilometers each travel will be.

K. Declercq et al. researched the distances traveled by a person [35]. The results for general displacements and displacements from work to home can be found in Table 4.3. These numbers are used to generate the number of kilometers traveled per displacement in the model. The percentages for work to home are used to simulate the two travels per day for an employed person and the other percentages are used for the other displacements.

Table 4.3: Distribution of average number of displacements per person per day by distance

Percentage of displacements per distance travelled		
Distance travelled [Kilometers]	**Normal displacements [percent]**	**Work to home [percent]**
0.1 to 0.2	1,912	1,69
0.3 to 0.5	5,373	1,69
0.6 to 1	9,840	1,69
1.1 to 2	13,019	6,44
2.1 to 3	9,337	7,16
3.1 to 5	13,975	12,11
5.1 to 7.5	9,800	8,35
7.6 to 10	7,496	9,65
10.1 to 15	7,727	11,72
15.1 to 25	8,321	15,52
25.1 to 40	5,403	11,91
40+	7,798	12,07

With all these statistics, a week schedule can be generated, and this schedule can be attached to a person. The process will be executed until the total population, which is represented by the variable *nOfPersons*, is reached that will be used.

4.2 Which mobility packages need to be offered?

Now that the possible customers of the MaaS provider are known, a MaaS provider has to construct a couple of mobility packages (Appendix 2). The goal of a MaaS provider is to find a limited amount of mobility packages that will convince the largest number of travelers to become actual customers. This happens by taking into account the traveling needs of the travelers, that are visualized in the week schedules (Appendix 1). Obviously a MaaS provider cannot offer an unlimited amount of mobility packages. The difficulty is to find the right combination of mobility packages to offer to the travelers. The amount of mobility packages offered to the travelers is represented by the variable *nOfPackages*. All the steps taken in the process of finding the right mobility packages are explained in this Section.

4.2.1 Populations travelling demand

The first step taken in the process of finding the right mobility packages is determining exactly what the travelling needs of the population are. Not only the number of kilometers that a traveler needs is important, but more precise, the number of kilometers per transport mode that a traveler needs. Hence, per person the MaaS provider needs to determine how much kilometers he or she needs for every transport mode. This is done while taking into account the preference of that particular traveler. As shown in Table 4.1, a traveler can have different preferences: time, money, a weighted combination of both or environmentally friendly. Every preference requires another approach to determine the number of kilometers per transport mode, these approaches are explained below.

In literature about the city of Ghent, some statistics were found about the displacement behavior of a traveler [23]. Those statistics are used as restrictions in this model. The report stated that a bike is used up to 10 kilometers and the bus from 0 to 15 kilometers. For displacements below 25 kilometers it is not interesting to take a train. The restrictions used in the model are shown in Table 4.4, most of them are based on the statistics that were found, others are assumptions that were taken (indicated with a star).

Table 4.4: Displacements restrictions based on statistics from Ghent (*: assumptions that were made)

Displacements restriction of the model

Transport mode	Minimum number of kilometers	Maxim number of kilometers
By foot	0	3*
Bike	0	10
Bus	0	15
Train	25	70*
Car	0	…

Time

The word is self-explanatory, a traveler with a preference of time always chooses for the fastest option when travelling. To compute how long it takes to complete a distance the speeds of the different transport modes have to be determined. Verhetsel et al. indicate the average speeds of the different transport modes [22]. Those average speeds are used in the model except the one of the car. The speed of the car is divided into three categories, for each category an assumption about the speed was made relatively to the average speed of a car found in literature. The average speed per transport mode used in the model can be found in Table 4.5.

Table 4.5: Average speed per transport mode

Average speed per transport mode

Transport mode	Average speed [kilometers/hour]
By Foot	6.9
Bike	15.4
Bus	18.7
Train	42.7
Car (below 10 km)	35
Car (below 35 km)	42
Car (above 35 km)	70

For a person with a preference of time the week schedule is investigated from the first moment till the last. If a moment is found were the traveler needs an number of kilometers, the possible transport modes that can be used for this travel are determined. This will be done by looking at Table 4.4 to see which transport modes are eligible. For the eligible transport modes, the number of needed kilometers is divided by the speed of that transport mode, which can be found in Table 4.5. Finally, the number of kilometers is assigned to the transport mode that takes the least time to complete the distance. This process is repeated until all the travels in a person's week schedule are assigned to a specific transport mode.

Money

If the preference of a person is money, he or she opts for the cheapest way possible to travel. A similar calculation is executed here, but instead of dividing the number of needed kilometers with the speed of the remaining transport modes, it is now multiplied with the cost per kilometer for the remaining transport modes. These costs were estimated in the real-life example of Section 3.1.3. Afterwards the number of kilometers is assigned to the transport mode that can travel this distance the cheapest. If all the travels of that person are assigned to a transport mode, the MaaS provider has a complete overview of the travelling needs of this person.

Environmentally friendly

This preference is one were a traveler chooses the most environmental friendly option to travel. The order of transport modes from most environmentally friendly to least environmentally friendly was assumed to be the following: by foot, bike, bus, train and as last the car. Assigning the number of kilometers to a transport mode, is done by first checking which transport modes are eligible. Then for the eligible transport modes the most environmental friendly one is chosen to assign the number of kilometers to.

Time and money

The final preference is the one were the traveler finds both time and money important. Instead of choosing for the fastest or cheapest option, this traveler tries to find a good balance between the two. The ideal transport mode for such a traveler is relatively fast and cheap at the same time, thus the traveler wants to minimize the time it takes and the money it costs to travel. Such an optimization is called a multi-objective optimization [36]. The weighted-sum approach is chosen to solve this optimization. This means that there is a weight attached to time and a weight to money. The weights depend on the preference of the person. The time to money ratio can be 50/50, 60/40 or 40/60. Because the lower the costs the better, and the higher the speed the better, some adjustments were made. These adjustments made sure that both the cost as the speed have about the same influence on the optimization. The final variable for the 50/50 ratio used to minimize is the following:

$$newVar = \frac{1}{2} * (100 - speed) + \frac{1}{2} * (100 * cost)$$

These variables are calculated for the transport modes that are suitable to travel such a distance. The one with the lowest value will be assigned the number of needed kilometers. Also here, this process has to be repeated until every travel in the week schedule is assigned to some transport mode, in order to get a complete overview.

To get a complete overview over the whole population and not over just a single person, one of the four approaches is done for every person, according to his or her preference. This will then generate a list per transport mode of needed number of kilometers. More specifically a list with a length of the population size. These lists contain the travelling demand of the whole population, which is needed to go to the next phase in the process.

4.2.2 Generate possible mobility packages

The lists per transport mode are now used to generate possible mobility packages, that are later on compared to each other to choose the best combination out of these packages. An easy way to generate a mobility package out of these lists, is by taking the average of every list and putting these averages in a mobility package. Obviously if this was the only mobility package that a MaaS provider would offer to the travelers, a lot of these travelers travelling demands would not be met or the difference with what they need would be too big. Hence, another approach was taken. First the lists were sorted from smallest number of needed kilometers to the largest number. After this, the lists were divided into a fixed number of sub-lists (*nOfSublists*), according to increasing number of kilometers.

A statistic is then used to represent every sub-list, group of travelers, with a single number of kilometers. The smaller the number of sub-lists, the bigger the number of travelers in such a list and the more difficult it is to represent this group of travelers realistically with one number of kilometers. The different statistics that are implemented in the model to represent a sub-list with a single number of kilometers are now described. How the sub-lists and the statistics are used to construct possible mobility package is visualized in Appendix 3.

Maximum out of list as the amount of needed kilometers

The name of this statistic speaks for itself, here the maximum number of kilometers is chosen to represent the needed number of kilometers of all the travelers that are in this sub-list. Instead of calculating the maximum, the last element of this sub-list can be taken because the sub-list is ordered from small to large. It is possible that a couple of numbers in the sub-list are significantly greater than the other numbers, than this statistic will probably not be a good one to represent the travel needs of all the persons in the sub-list.

Average out of list as the amount of needed kilometers

Another basic statistic that can be used is taking the average of the sub-list. Taking the average is done by first taking the sum of all the numbers in the sub-list and then dividing the sum by the length of the sub-list. Most likely this statistic will perform better than the previous one, because this statistic takes into account all the number of kilometers needed and not only the amount that is the largest.

Maximum out of list after outliers are removed

An improvement over taking the maximum is taking the maximum after the outliers are removed from the sub-list. Keeping the outliers will result in a deviating representation of the group travelers.

Average out of list after outliers are removed

The last and most promising statistic implemented in the model is the average without the outliers. The outliers are removed for the same reasons as in the previous statistic. In all probability, this will be the best option to choose. It will not be the optimal way to represent a group of travelers their travelling needs with one number of kilometers, but most likely the best out of the four that are implemented in the model.

After using one of these four statistics, an number of kilometers per sub-list is obtained. These numbers are used to construct the possible mobility packages. The higher the number of sub-lists, the higher the amount of possible mobility packages, which can be a problem if all the combinations of these packages have to be checked to see what the best combination is. For instance, 4 sub-lists return 4^4 (=256) possible mobility packages. If all these possible mobility packages are different then $\frac{256!}{(256-4)!*4!}$ (=174 792 640) different combinations of 4 packages can be made. Most likely some mobility packages will be exactly the same, so the duplicates can be removed. This will save some calculation time, but still a significant amount of combinations will have to be compared to each other. Hence, a balance needs to be found, that on the one hand the groups of travelers are represented realistically and on the other hand the calculation time remains manageable.

4.2.3 Mathematical model to solve to optimality

A MaaS provider would want to convince as many travelers as possible to become actual customers of its services. If the best combination of a fixed amount of mobility packages can be found out of the possible mobility packages then this goal is reached. The best combination refers to the combination that has the highest number of travelers that become actual customers when these packages are offered. As mentioned above, if the variable *nOfSublists* is set to 4 and *nOfPackages* is set to 4, at most 174 792 640 combinations need to be checked. Linear programming (LP) is used to optimize this mathematical problem [37]. The weight that is attached to every combination is the number of travelers that will become actual customers if that particular combination would be offered to them. How the decision is simulated that a traveler has to make, to choose to become a customer or not is explained further in this Chapter in Section 4.3. This optimization is a maximization problem, the combination with the most future customers has to be chosen. The variables used in this LP are:

$\mathrm{C_i} =$ $\mathrm{i^{th}}$ combination of possible mobility packages
$\mathrm{M} =$ amount of different combinations of the possible mobility packages
$\mathrm{nCustomers_i} =$ number of travelers that became customers after offering combination i

The actual LP that needs to be maximized is the following:

Maximize:

$$\sum_{i=1}^{M} nCustomers_i * C_i$$

Subject to:

$$\sum_{i=1}^{M} C_i = 1$$
$$\mathrm{C_i} \in \{0, 1\}$$

This is not a complicated LP, but the amount of combinations and the number of travelers makes the calculation very time consuming. Every combination needs to be checked for all the travelers, to see if one of the offered mobility packages meets his or her requirements. The amount of checks that need to be made is, the amount of combinations multiplied with the number of travelers. This model is solved by using the Gurobi solver in JAVA [38]. An example of an actual model constructed by the Gurobi solver is visualized in Appendix 4.

4.2.4 Mathematical model to solve to sub-optimality

After realizing that the optimal model would take a significant amount of time to calculate its results, a sub-optimal model was constructed to be able to simulate the model with an enormous amount of travelers. This model is also constructed and solved using the Gurobi solver in JAVA [38]. Instead of developing one sub-optimal model, two different ones were developed to compare them to each other. Afterwards a third one was formed by combining a sub-optimal model with the optimal model from Section 4.2.3. To simplify the objective function of this LP compared to the one used in the optimal model, the single mobility packages are used in the objective function and not the combinations of mobility packages. If there are 64 possible mobility packages, the sub-optimal model will have 64 variables in the objective function instead of $\frac{64!}{(64-4)!*4!}$ (=635 376) variables. What the exact sub-optimal models are and how they are implemented is shown below. An example of an actual model constructed by the Gurobi solver and the respective outcome of it is visualized in Appendix 5 and Appendix 6.

Difference between offered and needed kilometers

To choose a fixed amount of mobility packages out of the possible mobility packages some weight has to be attached to the possible mobility packages. In this sub-optimal model, the difference between the number of kilometers needed by a traveler and the amount of kilometers offered in the packages is used. More specifically, these differences for every person are summed up to a global difference per mobility package. This mathematical problem is a minimization problem, because the higher the difference the lower the change a customer will choose the mobility package. There are two options, as shown below, they both result in a different difference.

- Needed kilometers per traveler ≤ (offered amount * percentageAboveOfferedKilometers)
  → difference = |(offered amount * percentageAboveOfferedKilometers) – needed amount|

- Needed kilometers per traveler > (offered amount * percentageAboveOfferedKilometers)
  → difference = 1000

The variable *percentageAboveOfferedKilometers* is explained in detail in Section 4.3.1. This percentage is one that is greater than 100, because the assumption is made that a traveler will buy a mobility package even if its travelling needs are a couple percentages higher than the offered amount. In the second option the difference is set to 1000, this is a kind of penalty to make sure that this mobility package is not likely to be chosen. The variables of this LP and the LP itself are the following:

$\mathrm{m_i} =$ $\mathrm{i^{th}}$ possible mobility package
$\mathrm{M} =$ amount of possible mobility packages
$\mathrm{nOfPackages} =$ amount of actual mobility packages offered to the travelers
$\mathrm{diff_i} =$ summation of difference of every person its needs with possible mobility package i

Minimize:

$$\sum_{i=1}^{M} diff_i * m_i$$

Subject to:

$$\sum_{i=1}^{M} m_i = nOfPackages$$

$$\mathrm{m_i} \in \{0, 1\}$$

This LP will indicate the four mobility packages that have the lowest differences, this will result in a sub-optimal combination, but the optimization problem requires significantly less CPU time.

Number of matches for each possible mobility package

The weight chosen to be attached to the possible mobility packages here is the number of matches. This is the number of travelers that would become an actual customer of the MaaS provider. To simulate this, the algorithm explained in Section 4.3 is used. In contrast to the previous model, this mathematical model is a maximization. To avoid unnecessary lines of code in the implementation of the model this maximization problem is implemented as a minimization problem. Obviously then the number of matches were multiplied with -1 to get the same outcome as when it would be a maximization problem. The only difference in code with the previous model then is the weight attached to the possible mobility packages. This weight can be changed in the following variable:

$\mathrm{nOfMatches_i} =$ number of travelers that become a customer when mobility package i is offered

Combination of sub-optimal with optimal model

The last but not least sub-optimal model that is implemented is a combination of one of the above sub-optimal models and the optimal model explained in 4.2.3. More specifically, the sub-optimal model that performs best according to the analysis that will be made in Chapter 5 will be chosen to use in this model. First a number of mobility packages are generated with this sub-optimal model and those packages are the input of the optimal model. For example, the sub-optimal model searches the 30 mobility packages that perform best, then those 30 mobility packages are an input of the optimal model. Then $\frac{30!}{(30-4)!*4!}$ (=27 405) combinations need to be investigated by the optimal model, which is a lot less than 174 792 640 combinations. Out of the 30 mobility packages the best combination will be the result of the optimal model. This sub-optimal model its performance will probably come fairly close to the performance of the optimal model. The LP's used here are as follows:

$\mathrm{m_i} = \mathrm{i^{th}}$ possible mobility package
$\mathrm{M} =$ amount of possible mobility packages
$\mathrm{diff_i} =$ summation of difference of every person its needs with possible mobility package i

Minimize:

$$\sum_{i=1}^{M} diff_i * m_i$$

Subject to:

$$\sum_{i=1}^{M} m_i = 30$$
$$\mathrm{m_i} \in \{0,1\}$$

This LP will result in a list of 30 possible mobility packages, this list is the input in the optimal model.

$\mathrm{C_i} = \mathrm{i^{th}}$ combination of possible mobility packages
$\mathrm{nCustomers_i} =$ number of travelers that became customers after offering combination i

Maximize:

$$\sum_{i=1}^{27405} nCustomers_i * C_i$$

Subject to:

$$\sum_{i=1}^{27405} C_i = 1$$
$$\mathrm{C_i} \in \{0,1\}$$

How close all the sub-optimal models come to the optimal model will be tested in Section 5.1.3. Even if there is an optimal model the sub-optimal models are not completely a waste of time, because they generate a lower bound on the number of travelers that will become actual customers of the MaaS provider.

4.3 Link mobility packages to the travelers

After finding the best combination of mobility packages, those mobility packages are constructed and offered to the travelers. A function is implemented to see if one of the suggested mobility packages fulfills the needs of a traveler. If this is the case, the traveler becomes a customer of the Maas provider. There are two conditions that a mobility package must meet to be accepted by a traveler. The first one is the one that checks if the majority of their traveling needs are actually met. The second condition verifies the price: is it more advantageous to buy the mobility package than the buy all the subscriptions separately? How these conditions are implemented, is defined below.

4.3.1 Majority of the travelling needs met?

As already mentioned briefly above, the travelers will be satisfied if the majority of their travelling needs are met. If they have to buy one extra trip, besides the mobility package they bought, they will be more than willing to do so if this occurs only a few times a month. This phenomenon is represented by a percentage, named *percentageAboveOfferedKilometers.* Instead of comparing the travelling needs of a person with the number of kilometers offered in a mobility package, it is compared with the number of kilometers offered multiplied with this percentage. If the percentage is equal to 110%, this means that the number of needed kilometers has to be lower than 110% of the number of offered kilometers. This percentage will be varied during the analysis of the model to see what the impact of this variable will be on the linking process.

This part of the linking process checks if the majority of the travelling needs of a person or met. If this is the case than this traveler will be further investigated. If one of its needs is higher than a percentage of the offered number of kilometers, this person is classified as “not a match”.

4.3.2 Is the total cost more advantageous?

The travelers that met the first condition are now checked for the second condition. Here a comparison of the price paid for both two options is made. On the one hand the traveler can become a customer of a MaaS provider, then the price he or she pays is equal to the price of a mobility package. On the other hand, a traveler can choose to buy several subscriptions or single tickets from the separate transport providers itself, then the price paid is equal to the subscription prices and prices of a single ticket of the separate transport providers.

The price of a mobility package is calculated by multiplying the number of kilometers offered of each transport mode with the respective costs, those can be found in Section 3.1.3. Afterwards this total cost is multiplied with the variable *travelersBenefit*, this variable is equal to the discount that a traveler gets from a MaaS provider relative to the original selling prices of the separate transport providers. The *travelersBenefit* can be equal to the *purchaseDiscount* or equal to a part of it, this is a choice that the MaaS provider has to make. The *purchaseDiscount* is the discount that a MaaS provider gets from the separate transport providers for buying in bulk. The function of those two variables is showed in Section 3.2.1.

The subscription costs of the separate transport providers are the ones calculated in Section 3.1.3. The only problem is that these costs were based on the prices of a subscription, but when a traveler does not travel regularly with a specific transport mode, he or she will buy a single ticket instead of a subscription. If the amount of needed bus kilometers is lower than 30 kilometers per week, the cost of the bus for the traveler is switched from a price based on subscription prices to a price based on a single ticket. The same is done for the train, but with a limit of 100 kilometers. Those two limits are assumptions that were made and assumed to be static in the scenarios that are simulated in the next Chapter.

Now that the prices of both options are calculated, they can be compared to one another. Before comparing, the price when choosing for a mobility package of a MaaS provider is multiplied with a variable, named *percentageCostDifferenceAllowed*. This variable simulates the fact that people will approve the price of a Mobility package to be a little bit above the other price, just for the sake of comfort, because by becoming a customer of a MaaS provider, all the struggles of having different subscriptions with different transport providers disappear. In most cases, travelers are willing to pay a bit extra to make their life as easy as possible. Finally, the comparison can be made, if the final cost of a mobility package is higher than the price of buying all the subscriptions separately than the traveler decides to not become a customer. Such a traveler is labeled as “not a match”.

4.4 Cost and revenue calculation

If all the details about the travelers that become customers are known, the MaaS provider can calculate all its costs and revenues. This last step is needed to finalize the implementation model. On the basis of this information a conclusion can be made about the information services. Is it necessary to offer these services or can a MaaS provider have a complete valuable business case without offering information services?

4.4.1 Cost calculation for the mobility services

The costs of a MaaS provider that only offers the mobility services are visualized in Section 3.1.1. All the exact numbers for these costs used in the model are estimated in Section 3.1.3. The first cost is the total transport cost, this cost is calculated in the model by the following formula:

$$T = purchaseDiscount * \left((K_{bike} * C_{bike}) + (K_{bus} * C_{bus}) + (K_{train} * C_{train}) + (K_{car} * C_{car})\right)$$

T = total weekly transport cost of a MaaS provider
$\mathrm{K_i}$ = number of kilometers used by all the customers for transport mode i
$\mathrm{C_i}$ = cost per kilometer for transport mode i
$\mathrm{purchaseDiscount}$ = discount a MaaS provider gets from the different transport providers

The second cost is the cost of the integrated payment system, this cost can be calculated by taking 0.85% of the transport cost as mentioned in Section 3.1.3. The development and maintenance cost of the mobile application is a fixed cost of 0.27 euro per customer (Section 3.1.3). Hence, the exact cost of this is the multiplication of 0.27 euro and the number of customers. The shared cost for the mobility services and the information services is the cost to store and retrieve all the data. 10% of this cost is allocated to the mobility services and 90% to the information services, as mentioned in Section 3.1.2. This cost is estimated on 84 euro per terabyte per month (Section 3.1.3). The data collection happens primarily through GPS coordinates that are collected. The assumption is made that a GPS record is 20 bytes, (2 times 8 bytes for the latitude and longitude and 4 bytes for the timestamp). The amount of GPS records that are collected is assumed to be once every 10 seconds during the travel. Hence, in the model this cost is calculated by the following formula:

$$D = \left(\sum_{i=0}^{nOfCustomers} \left(\left((T_i * 3600)/10 \right) * (2 * 10^{-11}) * 0.10 \right) \right) * 84€$$

$\mathrm{D} =$ monthly cost to store and retrieve data
$\mathrm{T_i} =$ hours traveled for customer i each month

The last cost of the mobility services is 50% of the common cost of a MaaS provider, which is the cost to develop and maintain the website. This cost is estimated to 0.02 euro per customer. Hence, the exact cost of this is the multiplication of 0.01 euro and the number of customers.

4.4.2 Cost calculation for the information services

The cost of the information services consists of: the retrieval and storage cost of the data, the cost to analyze the retrieved data and finally 50% of the cost of developing and maintaining the website. The retrieval and storage cost of the data for the information services is the same as for the mobility services but here 90% of the amount of terabytes is used in the formula instead of 10%.

$$D = \left(\sum_{i=0}^{nOfCustomers} \left(\left((T_i * 3600)/10 \right) * (2 * 10^{-11}) * 0.90 \right) \right) * 84€$$

The cost of the website is the result of multiplying the number of customers with 0.01 euro. As mentioned in Section 3.1.3, no exact cost for analyzing data was found, this has to be kept in mind when the results are analyzed in Chapter 5.

4.4.3 Revenue calculation

The revenue of a MaaS provider can originate from two different sources: the sold mobility packages on one hand, and on the other hand the sold information reports. The yearly revenue generated from the mobility packages is calculated in the model by the following formula:

$$\mathrm{Rev_{mob}} = \left(\sum_{j=0}^{nOfPackages} \left(\left(\left(K_{j,bike} * C_{bike} \right) + \left(K_{j,bus} * C_{bus} \right) + \left(K_{j,train} * C_{train} \right) + \left(K_{j,car} * C_{car} \right) \right) * A_j \right) \right) * travelersBenefit * 52$$

$\mathrm{Rev_{mob}}$ = revenue generated through mobility services
$\mathrm{K}_{j,i}$ = amount of kilometer of transport mode i offered in mobility package j
$\mathrm{A_j}$ = number of packages sold of mobility package j
$\mathrm{C_i}$ = cost per kilometer for transport mode i
$\mathrm{travelersBenefit}$ = discount a MaaS provider gives to its customers

The revenue generated by the information services is not calculated in the model. The model is used to give a clear overview of the profit a MaaS provider can make on the mobility services. Is it possible to make a profit out of these services? Or is a MaaS provider forced to offer information services as well, if so, how much revenue should the information services generate? The results of the simulations made in Chapter 5 will provide an answer to these questions.

4.5 Conclusion

This Chapter is focused on the implementation model that was used. The implementation model has one central class, Main. This class is the driver of the model. First the population of travelers is generated via statistics found in literature. A traveler is characterized by a couple of personal characteristics and a week schedule that represents its travel needs for one week. When the population is generated, the Main class wants to create a full overview of the traveling demands of this population. This is done by attaching a number of needed kilometers for every transport mode to a person. This process happens by taking into account the preference of a person, each preference demands a different kind of algorithm to assign a travel to a particular transport mode. If this is done for every person a complete image about the traveling needs of the population is created.

This complete image was then used to decide which mobility packages to construct and offer to the travelers. Different statistics were used to represent their needed number of kilometers for a specific transport mode by a single number of kilometers. Afterwards these statistics were used to compose different mobility packages. These packages were used as input in a linear model. The output of the model is a fixed number of mobility packages that optimize the objective function. Two kind of models were used: an optimal model and a sub-optimal model. The optimal model always results in the best possible combination of mobility packages that a MaaS provider can offer to the particular population that was created. A sub-optimal model tries to approach the best solution as good as possible. To try to minimize the calculation time needed to get an optimal result a new sub-optimal model was constructed, this model is a combination of an already constructed sub-optimal model and the optimal model. How well these sub-optimal models perform according to the optimal model will be tested in the next Chapter.

After finding the best combination of mobility packages, these packages were virtually offered to the travelers. An algorithm – called the linking process of the mobility packages to the travelers - is used to see if a person would buy a particular mobility package or not. Two conditions need to be met in order to get a positive result in the linking process: (1) fulfilling the majority of the traveling needs of the traveler and (2) having a price that is lower than the combined pricing of the separate transport providers. After the linking process the exact number of travelers that became customers, is known.

Last but not least, the actual customers were used to calculate the costs and revenues of the MaaS provider. The costs of the MaaS provider were calculated by two separate costs in the model: the costs of the mobility services and the costs of the information services. The revenue is divided into the same two categories. On the basis of profit originating from the mobility services, a decision about the information services can be made. Are information services needed for a MaaS provider to make a profit or not? These questions and the analysis of the implementation model will be discussed in the next Chapter.

5
Analysis of different simulation scenarios

Now that the model is constructed in JAVA, it can be used to simulate different scenarios, to see which parameters have a significant impact on the business case. What this impact exactly is, will be investigated by ranging the influential parameters of the model. These parameters are: *travelersBenefit*, *purchaseDiscount*, *nOfSublists* and *nOfPackages*. To get results that are as reliable as possible the simulations of a single test are done with exactly the same population. Other parameters are assumed to be static all the time (i.e. the maximum percentage of kilometers that a traveler is willing to buy on top of the amount that the mobility package offers (*percentageAboveOfferedKilometers*) will be set to 10%, the parameter that simulates the fact that a person will approve the cost of a mobility package to be a bit more expensive than what they would have to pay to the separate transport providers (*percentageCostDifferenceAllowed*), is fixed to 10%). The type of scenarios and their respective results are discussed during the next Sections.

5.1 Reference scenario testing

First a reference scenario is constructed, of which the setup of the parameters is listed in Table 5.1. This reference scenario will be used to fix a number of other parameters. The first test simulates the reference scenario for a couple of population sizes, this test is done to find a sample size that is large enough to do the remaining of the tests with. The second test tries to find the best statistic to use to represent the traveling needs of a group of persons. Finally, the reference scenario is also used to evaluate the performance of the different sub-optimal models in relation to the performance of optimal model.

Table 5.1: Setup of the parameters in the reference scenario

Reference scenario	
Parameters	**Parameter value**
nOfSublists	4
nOfPackages	4
PurchaseDiscount	15 %
TravelersBenefit	15 %
Maximum percentage of kilometer that a traveler is willing to buy on top of mobility package	10 %
Percentage of cost difference that a traveler is willing to pay for	10 %
Statistic	Average when outliers removed
Mathematical model	Optimal

5.1.1 Determine sample size

The calculation time of the optimal model is already very extensive due to all the possible combinations of mobility packages that need to be checked, as described in Section 4.2.3. Because of this, it would be helpful if the population could be kept at a moderate size. Hence, the minimal sample size needed to do the simulations is checked in this Section. A simulation of the reference scenario is done with increasing population size (Figure 5.1). This size varies from 10 travelers up to 200 000 travelers. Higher population sizes (500 000 and higher) generate out of memory errors and were hence not feasible to simulate. The percentage of travelers that become actual customers of the MaaS provider stagnates when the population size is 100 000 or more. This suggests that a stable sample size to do the remaining test with is equal to 100 000. The effect on the computation time of the model is noticeable when the population size is set to 100 000 instead of 200 000, as the computation time reacts approximately linearly to the population size. To be more precise, it took the model 16 hours and 17 minutes to finish its calculations with a reference scenario and a population size of 200 000 travelers. By reducing the population size to 100 000 travelers, the computation time was more than halved, more specifically just under 8 hours was needed by the model to do the calculations. An example of the output that shows all the results that are generated by the model can be found in Appendix 7.

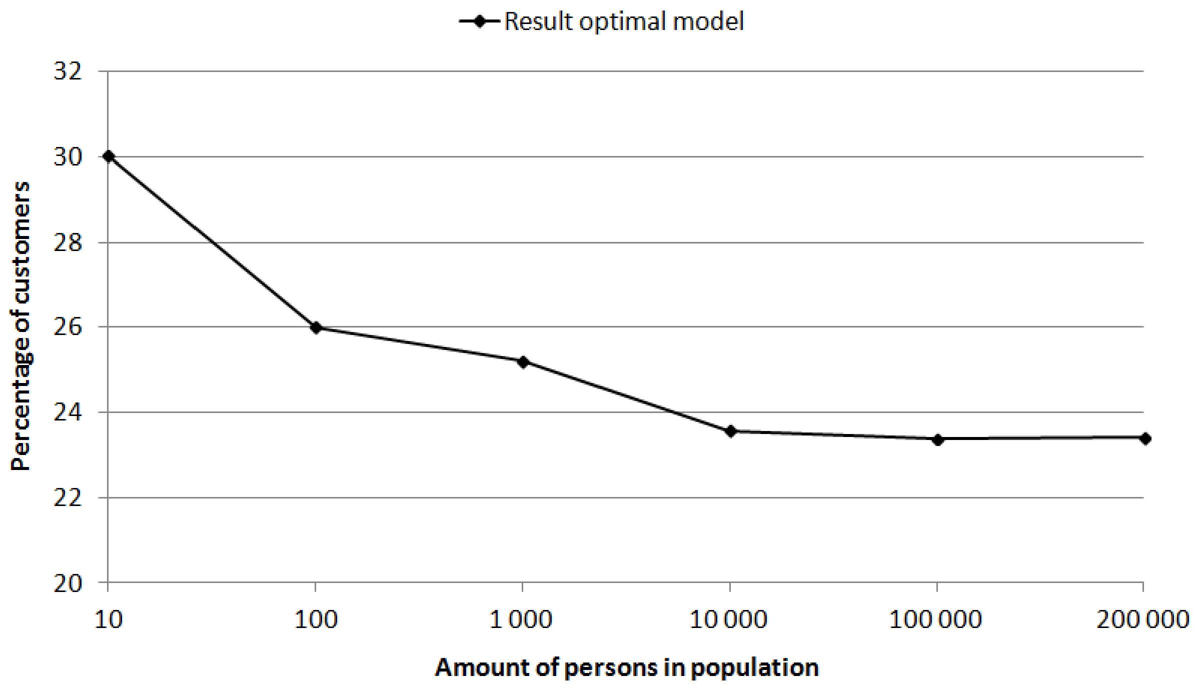

Figure 5.1: Percentage of travelers that become actual customers with increasing population size (reference scenario)

5.1.2 Determine the best statistic to use to represent a group of travelers

The second parameter that will be determined by simulating with a reference scenario is the statistic that is used to represent the travelling needs of a group of travelers by a single number of kilometers. How these statistics exactly work is described in Section 4.2.2. Hence, four simulations are executed on the reference scenario. The performance indicator for these simulations is the percentage of travelers that become actual customers. This percentage depends on the mobility packages that the MaaS provider offers, hence also on the statistic used, because the statistic determines what the possible mobility packages will be (Appendix 3). The results of these simulations are listed in Table 5.2.

Table 5.2: Percentage of travelers that become actual customers for every statistic implemented in the model

Basic testing with different statistics (reference scenario)

Statistics	Percentage of travelers that become customer
Average	18.06
Average when outliers removed	23.37
Maximum	31.84
Maximum when outliers removed	27.76

Out of the results we can conclude that taking the maximum number of needed kilometers of a group of travelers is the best way to represent the traveling needs of the whole group of travelers in the model that was implemented. This is due to the implementation of the linking process, explained in Section 4.3, more specifically on the first part of this process as it checks if the travelling needs of the traveler are met. When taking the average as statistic, a part of the group of travelers will be already excluded due to the fact that their traveling needs are higher than the average. Because the maximum statistic scored the highest on the test all the remaining scenarios will be simulated with this statistic.

5.1.3 Optimal model versus sub-optimal models

By simulating the reference scenario with a population size of 100 000 travelers and the maximum statistic but with different optimization models, the performance of these optimization models can be compared to each other. How these mathematical models are constructed and implemented in the model can be found in Section 4.2.3 and Section 4.2.4. The results of these simulations are listed in Table 5.3. The calculation time for the same scenarios in different tests throughout this Chapter can vary a bit due to the fact that two different test machines were used that do not have the exact same processor capacity.

Table 5.3: Comparison of the performance of the different optimization models

Performance optimal model versus sub-optimal models

Model	Percentage of travelers that become customer	Calculation time
Optimal	31.77	9 hours 17 minutes
Sub-optimal (differenceCost)	0.06	28 seconds
Sub-optimal (nOfMatches)	20.13	47 seconds
Combination sub-optimal (nOfMatches) and optimal	31.77	28 minutes 45 seconds

The first sub-optimal model is the one that uses the difference in numbers of kilometers between what the traveler needs and what the mobility package offers as the weights. As seen in Table 5.3 the performance of this sub-optimal model is very weak. It differs greatly from the result obtained when using the optimal model. This very low percentage of travelers that become actual customers is mainly attributable to the statistic, the maximum, used. The difference between needed number of kilometers and the maximum needed number of kilometers in a group of travelers is large for most of the travelers in that group. Due to this difference, a large weight will be attached to that mobility package, resulting in not picking the mobility package by the mathematical model.

The second sub-optimal model performs significantly better than the first one, due to the different weights that are used in the two models. In this model, the number of matches is used as weight, this is the number of travelers that become actual customers when that mobility package would be offered. Still, the gap between this sub-optimal model and the optimal model is too large to be able to say that this sub-optimal model's performance approaches the performance of the optimal model. Hence, the sub-optimal model cannot be used to replace the optimal model in the remaining simulations.

As the low performance of the differenceCost sub-optimal model could potentially be attributed to the statistic used (maximum), both sub-optimal models were simulated according to the reference scenario but with the average as statistic, more specifically the average after the outliers are removed. As showed in Table 5.4, the sub-optimal model (differenceCost) performs much better when this statistic is used, thus the conclusion that the previous result had to do with the maximum used as statistic is confirmed. But still the sub-optimal model with the number of matches chosen as weights performs better than the other sub-optimal model, no matter which statistic is used. Hence, we can conclude from the results in Table 5.3 and Table 5.4, that the sub-optimal model (nOfMatches) performs better than the sub-optimal model (differenceCost).

Table 5.4: Comparison of the two sub-optimal models (statistic: average after outliers removed)

Performance two sub-optimal models

Model	Percentage of travelers that become customer	Calculation time
Sub-optimal (differenceCost)	11.663	29 seconds
Sub-optimal (nOfMatches)	13.797	27 seconds

A third and last sub-optimal model was constructed using the optimal model. The problem with the optimal model was the amount of variables in the objective function, as explained in Section 4.2.3. To reduce this amount, a sub-optimal model is first used to already exclude a significant amount of mobility packages. The sub-optimal model (nOfMatches) is chosen as the sub-optimal model, because its performance is significantly better than the other sub-optimal model. In this simulation, the best 27 mobility packages from the sub-optimal model were retained, reducing the original number of mobility packages (54) by half. This reduced amount of mobility packages is used as input for the optimal model. The combination of the sub-optimal model and the optimal model is expected to approach the optimal solution because the mobility packages that form the best possible combination will most likely still be present in the 27 mobility packages that the sub-optimal model gives as output. As seen in Table 5.3, this combination model has the same result as the optimal model, on top of that it took significantly less time to calculate it. Instead of checking all combinations of 54 different mobility packages which results in $\left(= \frac{54!}{(54-4)!*4!} = 316\ 251\right)$ unique combinations, it only had to check all combinations of 27 different mobility packages, which results in $\left(= \frac{27!}{(27-4)!*27!} = 17\ 550\right)$ unique combinations.

Now that the result in Table 5.3 suggest that both the optimal and the last sub-optimal model will perform exactly the same for the tests that will still be carried out, some other simulation were done to make sure that this conclusion is valid. The optimal and sub-optimal model were simulated for scenarios with two different statistics for increasing population sizes. Table 5.5 shows the results of these simulations. The percentage of travelers that become customers is used as performance indicator of the two mathematical models. It is obvious that the combination of the sub-optimal model and the optimal performance exactly the same as the optimal model. Hence, the conclusion that was derived from the results of Table 5.3 are confirmed by these extra simulations. Because of this the remaining simulations are done with the sub-optimal model instead of the optimal model. Due to this decision a lot of computation time will be saved.

Table 5.5: Percentage of travelers that become actual customers with different simulation scenarios for the optimal model and the combination of the sub-optimal and optimal model

Optimal model versus Combination sub-optimal (nOfMatches) and optimal

	averageWithoutOutliers		maximum	
Population size	**Optimal**	**Combination sub-optimal and optimal**	**Optimal**	**Combination sub-optimal and optimal**
10	30	30	80	80
100	28	28	33	33
1 000	23,1	23,1	29,8	29,8
10 000	24,03	24,03	32,39	32,39
100 000	23,167	23,167	31,676	31,676

To conclude the three tests that were done in this Section, a final reference scenario is constructed. This scenario will be used throughout this Chapter to do all the other simulations, while varying specific parameters. Table 5.6 shows the scenario used in the upcoming simulations.

Table 5.6: The updated reference scenario

Updated reference scenario

Parameters	Parameter value
Population size	100 000 travelers
nOfSublists	4
nOfPackages	4
PurchaseDiscount	15 %
TravelersBenefit	15 %
Maximum percentage of kilometer that a traveler is willing to buy on top of mobility package	10 %
Percentage of cost difference that a traveler is willing to pay for	10 %
Statistic	Maximum
Mathematical model	Combination sub-optimal (nOfMatches) and the optimal model

5.2 Varying purchaseDiscount and travelersBenefit

Now that the basic variables of the model are set to their optimal settings the impact of some variables on the business case of the MaaS provider can be investigated. The variables that are investigated in this Section are the variables that represent the discount a MaaS provider receives and gives, more specifically the *purchaseDiscount* and the *travelersBenefit*. Those two variables are related to each other (see Section 3.2.1, Figure 3.2 and Figure 3.3). The impact of both the variables is checked by varying them in a specific interval, first separately, then together. The focus of this investigation lays on the impact of both the variables on the mobility aspect of the MaaS provider, more specifically on the mobility costs and revenue of the MaaS provider. At which point a MaaS provider is required to also offer information services to its customers, will be clearly visible in the graphs that are generated about the results of these simulations.

5.2.1 Varying purchaseDiscount

If only the discount that a MaaS provider gets from its transport suppliers is varied and the discount it gives to its customers is fixed to 15%, the percentage of travelers that become customers of the MaaS provider stays the same for every scenario simulated. This is logical because the *purchaseDiscount* variable has no influence in the decision process of a traveler. The *purchaseDiscount* is varied from 0% to 50%, in increments of 5 % each. A discount of 0% means that the MaaS provider has to pay the full cost to its transport suppliers; if it only has to pay half of the full cost to its suppliers the discount will be equal to 50%. The decision was taken to stay in this interval because a discount of more than 50% is very unlikely to receive from the separate transport providers. The impact of the discount that a MaaS provider gets from the separate transport providers is reflected in the yearly profit that the MaaS provider makes. The results of the scenarios simulated can be found in Figure 5.2.

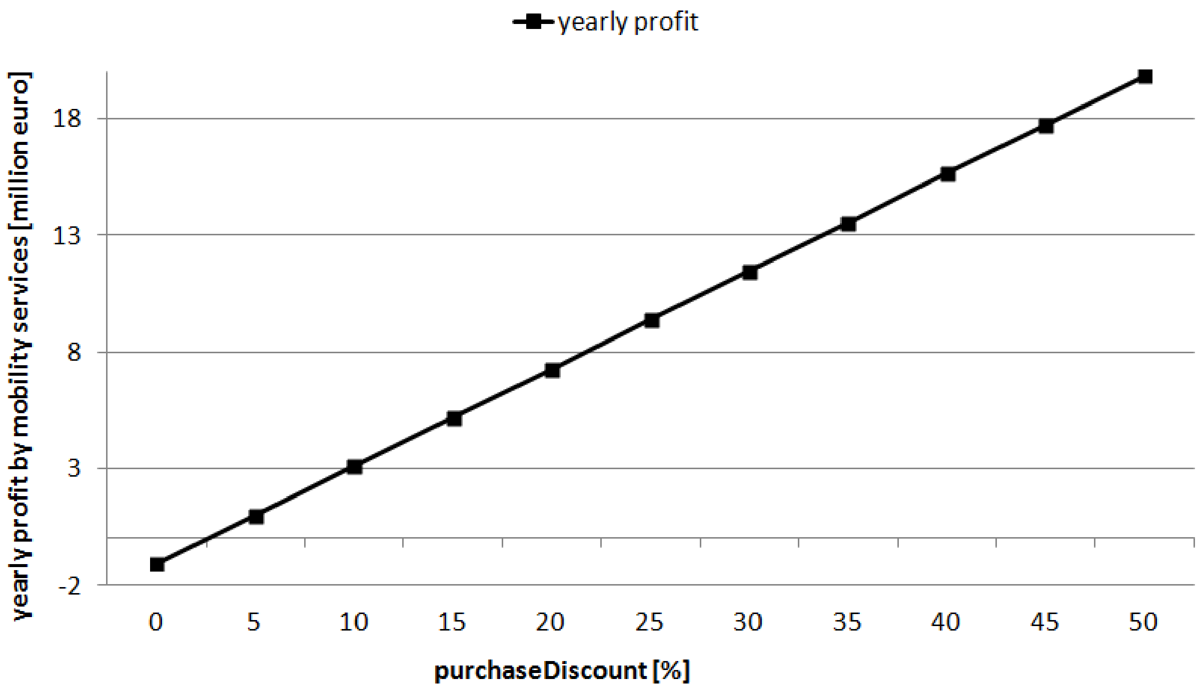

Figure 5.2: Yearly profit from a MaaS provider generated by the mobility services with varying purchase discount received

The yearly profit increases linearly according to the purchase discount received, this yearly profit is made by 32% of the travelers that became customers, thus 32 000 out of the 100 000. The yearly profit varies from around 1 million loss for no discount to almost 20 million profit for a 50% discount rate. The mobility cost of the MaaS provider stays the same for every scenario simulated because in all the simulations the same group of travelers became actual customers. If the mobility costs stay the same and only the discount changes on that particular cost, then obviously, the yearly profit will increase linearly according to the discount increase. A conclusion that can be drawn out of this test is that a MaaS provider is perfectly able to have a valuable business model with only offering mobility services if it gets a certain purchase discount from its transport suppliers. If it does not get a discount or not a substantial one, it might be required to offer the information services in addition to the mobility services. On the contrary, the Maas provider can always use the information services to even further increase its profits.

5.2.2 Varying travelersBenefit

Now the reverse situation is simulated to check what the impact of the discount that a traveler gets from the MaaS provider is, on the business case of the MaaS provider. The *travelersBenefit* is also varied from 0% to 50%, in increments of 5 % each. For the same reasons as above, a *travelersBenefit* of more than 50% would be very unrealistic, hence the maximum is 50%. The *purchaseDiscount* stays fixed to 15% in all the scenarios simulated. As already mentioned, the *travelersBenefit* has an influence on the decision process of a traveler, this is the process that decides if a traveler becomes an actual customer or not. If the *travelersBenefit* increases, the chance of saving money when buying a mobility package instead of separate subscriptions with the transport providers increases as well, hence the number of travelers that become customers increases (reflected in the blue graph in Figure 5.3).

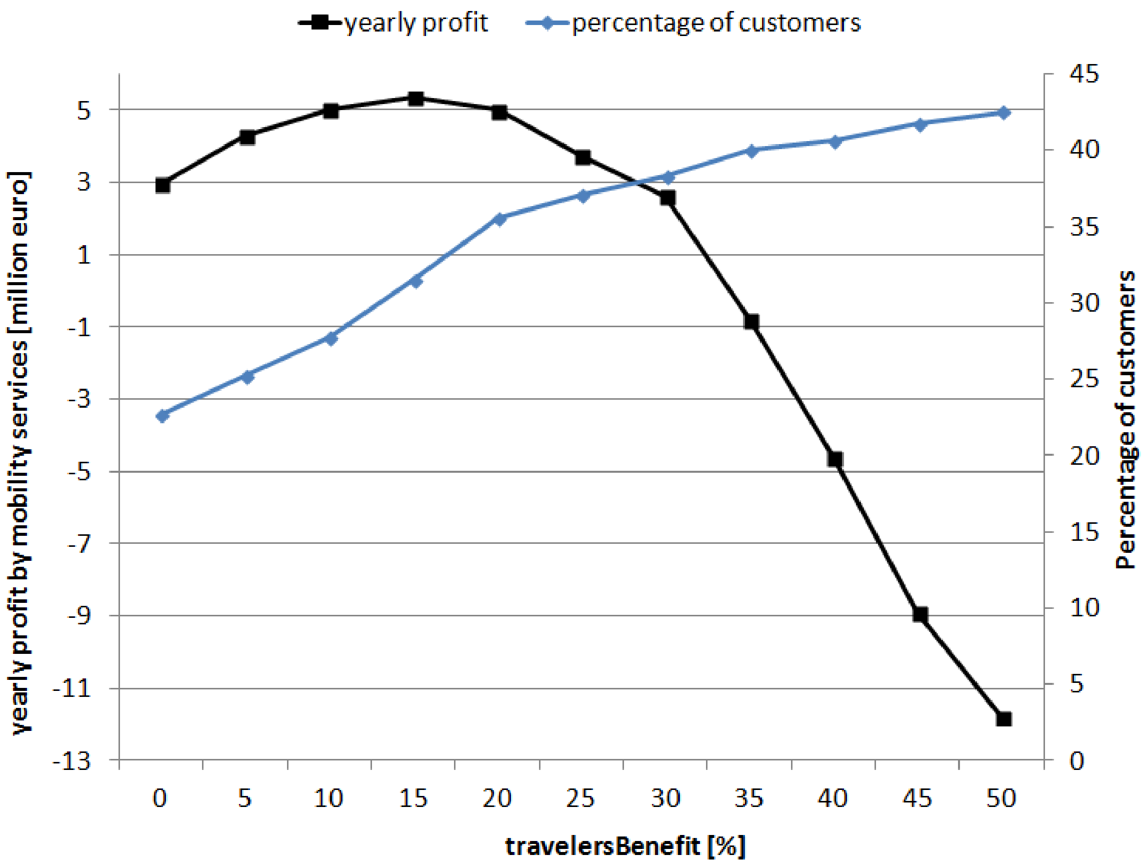

Figure 5.3: Yearly profit generated by the mobility services and percentage of travelers that become actual customers with varying travelersBenefit

When investigating both the increase of percentage of travelers that become customers and the yearly profit generated, Figure 5.3 shows that there is an optimal point in terms of yearly profit. First, the yearly profit rises together with the percentage of travelers that become customers of the MaaS provider. But when the *travelersBenefit* becomes larger than 15% the yearly profit starts to decrease very fast. At the point where both the *travelersBenefit* and the *purchaseDiscount* are equal to 15%, the MaaS provider uses the discount it gets from the transport providers entirely to give to the travelers as discount. When the *travelersBenefit* is lower than the *purchaseDiscount*, the MaaS provider will keep a part of the *purchaseDiscount* as a direct profit instead of giving the discount entirely to the travelers. This direct profit is reflected in the slope of the black graph between two points. This slope decreases as the point approaches where both the *purchaseDiscount* and the *travelersBenefit* are equal, because then the direct profit decreases. On the other hand, if the *travelersBenefit* is larger than the *purchaseDiscount*, this causes the MaaS provider to pay more mobility costs than there is mobility revenue. The MaaS provider only makes losses when the difference between the *travelersBenefit* and the *purchaseDiscount* is higher 15%. The fact that the profit is still positive when the *travelersBenefit* is 30% and the *purchaseDiscount* only 15%, can be assigned to the fact that the travelers do not use all the kilometers of transport services that are available in their mobility package, even though they paid for it.

Now the MaaS provider has a strategic decision to make, does it want to expand its market share or does it want to make as high as a profit as possible on short-term. If the MaaS provider chooses to go for the short-term profit, it will choose to entirely use the discount it received from its transport suppliers to provide as a discount for its customers. This will yield a stable customer base and a certain profit for the MaaS provider.

If the MaaS provider bases its decision on the profit in the long run, it chooses to give a higher discount to the travelers, thus increasing the *travelersBenefit*, resulting in an increase of its market share. An advantage of having a larger market share is the leverage that a MaaS provider has when negotiating the contracts with its transport suppliers. If its market share is higher, the economies of scale will play a bigger role, which will give the transport providers the capability to give the MaaS provider a bigger purchase discount, hence resulting in a higher yearly profit (as shown in Figure 5.2). But in giving this high discount to its customers, the yearly profit of a MaaS provider decreases and even turns into a loss. Hence, the MaaS provider has to find a way to make extra revenue so its profit becomes positive again. The MaaS provider can choose to offer information services. The cost to offer information services consists of three different costs: developing and maintaining the website, storage and retrieval cost of the data, and cost to analyze the data. The sum of the first two costs is equal to 476 euro for a *travelersBenefit* of 50% and a population size of 100 000, the last cost is not included in the model and thus should be kept in mind throughout this analysis. If we know that Proximus, a Belgian telecommunications company, sells reports about its customers for at least 700 euro, selling the information gathered by the MaaS provider could generate a significant extra amount of revenue [39]. As mentioned in Section 3.2.2, there are different kind of reports, which will result in different prices for these reports. What kind of revenue this service could create is not in the scope of this master dissertation.

The same conclusion as in the previous Section can be made, a MaaS provider is perfectly capable of being profitable with only offering mobility services, but the profitability depends strongly on the characteristics of the MaaS ecosystem. Not all characteristics can be directly influenced by the MaaS provider (e.g. the purchase discount). Hence it is possible that the MaaS provider will be obliged by the characteristics of the MaaS ecosystem to offer the information services so it has a valuable business model.

5.2.3 Varying both purchaseDiscount and travelersBenefit at the same time

Instead of keeping one of the two variables static, both the variables are now varied, affecting the percentage of customers, due to the *travelersBenefit*, and at the same time affecting the yearly profit made by the MaaS provider, due to the purchase discount that changes.

purchaseDiscount equals travelersBenefit

First the impact of both variables having the same value is simulated. Both variables are varied from 0% to 50%, with increments of 5% (Figure 5.4).

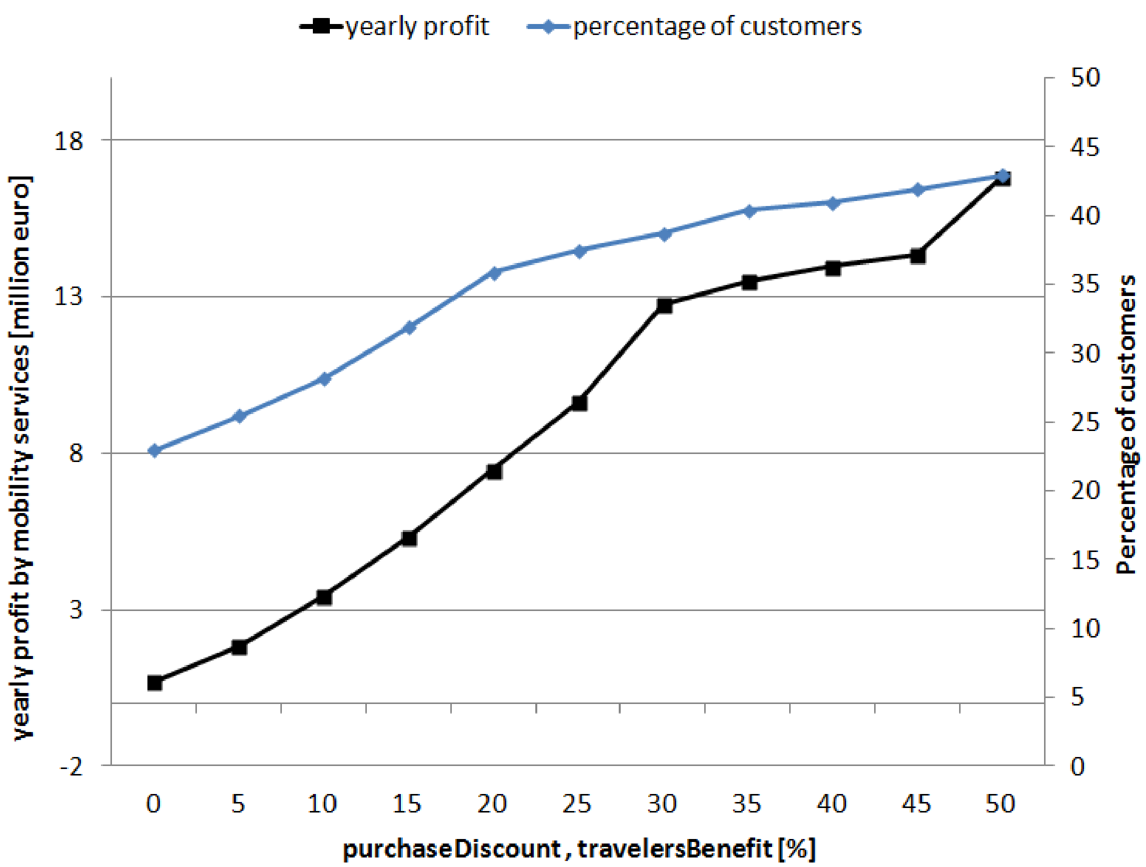

Figure 5.4: Yearly profit generated by the mobility services and percentage of travelers that become actual customers with varying purchaseDiscount and travelersBenefit

This result is not surprising, if both variables increase then both the yearly profit as the percentage of travelers that become customers will increase. The increase in yearly profit is not as large as when the *travelersBenefit* was fixed to 15%. This is because now the purchase discount received from the different transport providers is entirely given to the travelers in the form of a discount, the *travelersBenefit*, instead of keeping a part as direct profit. By looking at the graph taking 50% as *purchaseDiscount* and *travelersBenefit* would be the best option to aim for a yearly profit as high as possible. But in real-life 50% purchase discount is a very high number, this is very unlikely that a transport provider will sell its services for half the price. In real life, the purchase discount will be a fixed number that the MaaS provider cannot change drastically. Hence, the MaaS provider will have to choose the percentage of discount it gives to its customers according to the discount it received. To make this decision both the short-term and long-term should be taken into account, as was explained before.

All possible combinations of purchaseDiscount and travelersBenefit

To make it easy for the MaaS provider to choose the discount it has to give to its customers for a given purchase discount in order to maximize its yearly profit, all the combinations of those two variables are simulated. Both the *purchaseDiscount* as the *travelersBenefit* are simulated for values ranging from 0% up to 50%, in increments of 10%. Figure 5.5 shows the yearly profit of the MaaS provider on different graphs, a graph for every possible value of the *travelersBenefit*: the lower the *travelersBenefit*, the smaller the increase in yearly profit and the higher the *travelersBenefit*, the larger the increase. This is due to the percentage of travelers that become customers of the MaaS provider. If the *travelersBenefit* is low, the percentage of travelers that become customers will be low and this leads to a small customer base to make a profit on. On the other side, if the *travelersBenefit* is high, the customer base will be very large, but will also lead to a higher effect of the *purchaseDiscount* on the profit the MaaS provider makes. The black graph shows that for a *travelersBenefit* of 50%, which resembles in a large customer base, the MaaS provider makes a significant loss if the *purchaseDiscount* is not high enough.

To get the highest yearly profit a MaaS provider has to set its *travelersBenefit* to the same percentage as the *purchaseDiscount* it receives, unless the *purchaseDiscount* is higher than 30%, then it has to keep its *travelersBenefit* to 30%. This can be seen in Figure 5.5, at a *purchaseDiscount* of 40% the MaaS provider will make the highest profit by setting its *travelersBenefit* to 30%. Not setting the *travelersBenefit* to the same percentage as the *purchaseDiscount* will mean that the customer base will be a bit smaller but this will generate a direct profit for the MaaS provider. The conclusion that can be made here is that the MaaS provider should try to increase its market share up until a certain point. From that point on it has to keep its *travelersBenefit* stable so it earns some direct profit through the *purchaseDiscount* received. Through analysis on the travelers' population, a MaaS provider knows exactly what percentage of discount to give to its customers for every possible purchase discount received.

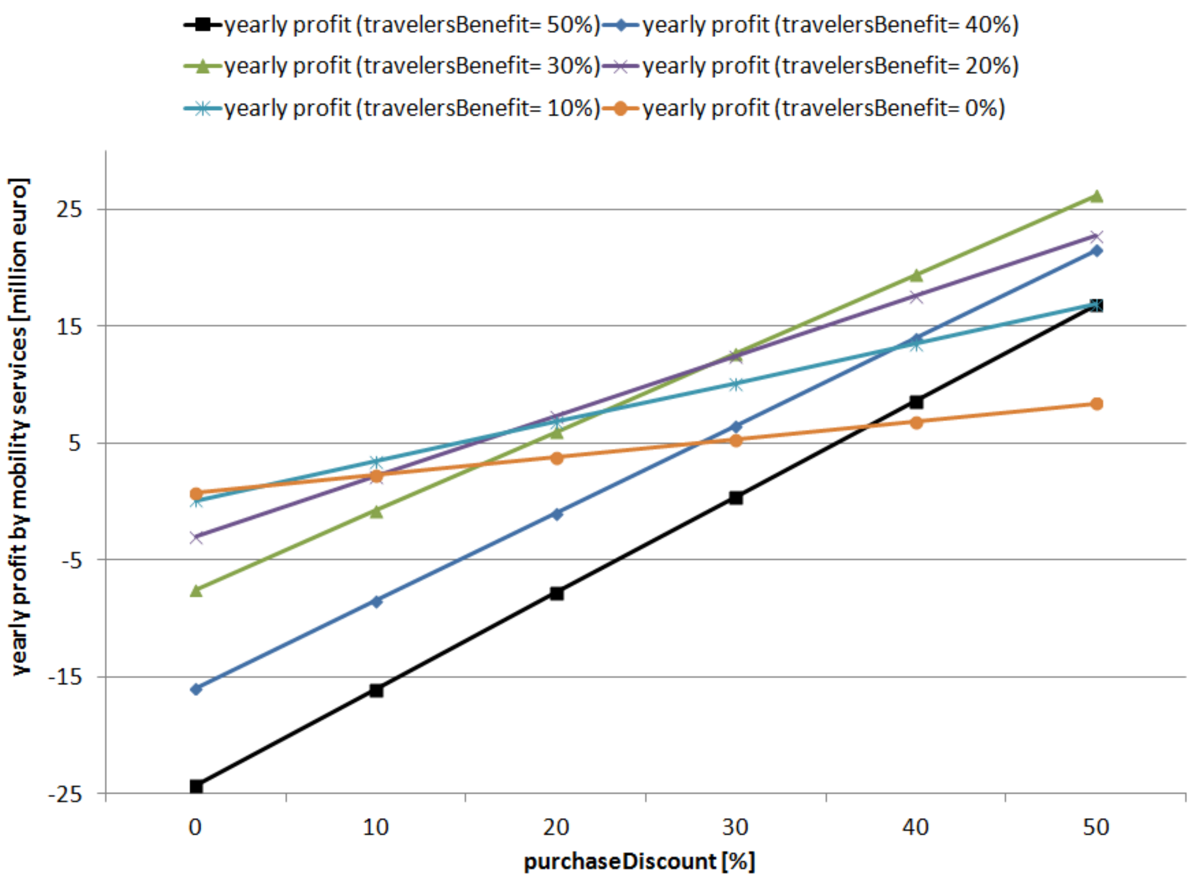

Figure 5.5: Yearly profit generated by the mobility services with varying travelersBenefit and purchaseDiscount

5.3 Varying number of sub-lists used to represent whole population and the number of packages offered to the travelers

The purpose of the sub-lists in the model is described in detail in Section 4.2.2 and Appendix 3. Such a sub-list contains the traveling needs of a group of travelers for a particular transport mode. What the impact of this parameter will be on the outcome is researched in this Section. Next to this parameter, also the number of packages is varied. The number of packages represent the amount of mobility packages that a MaaS provider offers to the population to try to convince the travelers to become actual customers.

5.3.1 Varying number of sub-lists

By increasing the number of sub-lists, the number of travelers that are represented by the maximum statistic in a single sub-list is decreased. When the number of sub-lists increases, the number of possible mobility packages increases as well (leading to more combinations of mobility packages to be researched, and higher calculation time – forcing us to choose for the sub-optimal model). How the yearly profit of a MaaS provider and the percentage of travelers that become actual customers react on the increase of the number of sub-lists is represented in Figure 5.6 (keep in mind that the number of mobility packages offered by the MaaS provider is fixed to four).

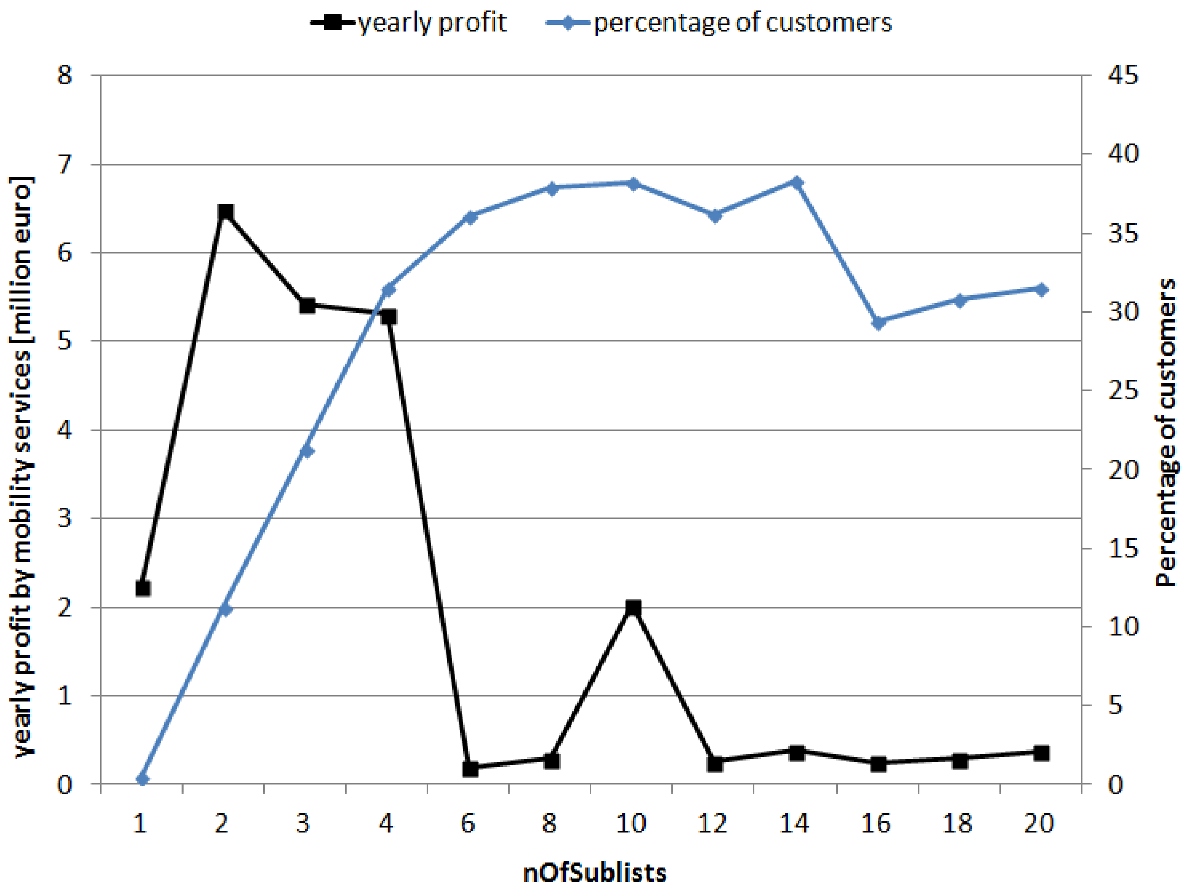

Figure 5.6: Yearly profit generated by the mobility services and percentage of travelers that become actual customers for varying number of sub-lists

When the number of sub-lists increases, the percentage of travelers that become customers will increase as well. This is due to the fact that with smaller sub-list sizes, the difference between the traveling needs of the travelers in the same group is smaller. Because of mobility packages that better match the needs of the travelers, a larger percentage of them will become customers.

But when the number of sub-lists keeps increasing, a saturation point is reached: the number of travelers in a sub-list will become too small, causing the mobility package to be too tailored to a single group of travelers. Because of this, the chance of a traveler from another group deciding to buy this mobility package will decrease. Due to this and the limited amount of mobility packages that are offered by a MaaS provider, the percentage of travelers that become actual customers will decrease.

A similar observation can be made for the yearly profit of the MaaS provider: from a certain number of sub-lists, the profit drops significantly. This is due to the same reasons, when the offered mobility packages suit the needs of the travelers very well, the travelers will use almost everything in their mobility package, hence taking away a part of the MaaS provider's profit source. The exception when the number of sub-lists is equal to 10 can be explained by the fact that there will be a mobility package offered that does not meet the demand of the travelers very strictly, thus generating a lot of direct profit for the MaaS provider. But generally, the yearly profit of the MaaS provider approximately stays the same from a certain number of sub-lists. The results of Figure 5.6 confirm that setting the number of sub-lists to four in our reference scenario was a well-taken decision.

5.3.2 Varying number of packages

Instead of varying the number of sub-lists, the number of packages offered to the travelers is varied in this test. The more mobility packages the MaaS provider offers, the more travelers it can convince to become customers. The extreme case is that a single mobility package per traveler could be offered, leading to all travelers to become customers. But this is not realistic, a transport provider only offers a couple of different mobility packages. For this test, the number of packages offered to the travelers varies from 1 package up to 10 packages, in increments of 1 package. During the entire time of the test the number of sub-lists is fixed to 4.

By increasing the number of packages offered, the number of combinations of mobility packages increases as well. The optimal model gets 27 different mobility packages, with these 27 packages $\left(=\frac{27!}{(27-4)!*4!}=17\ 550\right)$ combinations of four different mobility packages can be made. But with the number of packages set to 6, this amount of combinations increases to $\left(=\frac{27!}{(27-6)!*6!}=296\ 010\right)$ and if set to 8, the amount of different combinations is equal to $\left(=\frac{27!}{(27-8)!*8!}=2\ 220\ 075\right)$. The time to calculate the solution when the number of packages is set to 6 was around 11 hours. With around ten times more combinations for the number of packages set to 8, the calculation time is estimated to be around 110 hours. Because of this, the decision was made to only take the best 17 mobility packages out of the sub-optimal model as input for the optimal model when the number of packages is bigger than 4, this to keep the computation time manageable.

The results of these simulations are shown in Figure 5.7. The percentage of travelers that become customer increases according to the number of packages offered, up until this number is equal to 4. From then on, the percentage of travelers that become customers as well as the yearly profit approximately stays the same. The big jump in yearly profit taken when the MaaS provider goes from 3 mobility packages offered to 4 packages is caused by the way these mobility packages are formed. Due to the fact that a person's preferences in terms of traveling are very difficult to simulate by a program, the traveling needs of a person are assigned unilaterally to a transport mode. Because of this, a significant amount of the persons that are generated have a traveling need that almost only makes use of a single transport mode. Due to the fact that a MaaS provider constructs its mobility packages on the basis of the traveling needs of the population, mobility package that offer a number of kilometers for only a single transport mode are constructed. These packages are chosen by the optimal model because this model scores the combination of mobility packages with the number of customers that would buy one of the offered mobility packages.

The mobility packages that are offered by the MaaS provider when the number of packages is set to 3 can be found in Appendix 8. As reasoned above, these three mobility packages offer transport services of a single transport mode (more specifically: 41 kilometers of car, 40 kilometers of bus and 24 kilometers of bike). The simulation with the number of mobility packages offered set to 4, chose the package showed in Appendix 9. The first three packages are roughly the same but the package that is offered extra is a bit different. This package offers 138 kilometers of bike, 40 kilometers of bus and 1050 kilometers of car. Obviously, this package will generate a lot more revenue because the number of kilometers that are sold to the customers is significantly higher than in the other three packages. This conclusion confirms our initial choice to offer four mobility packages in the reference scenario.

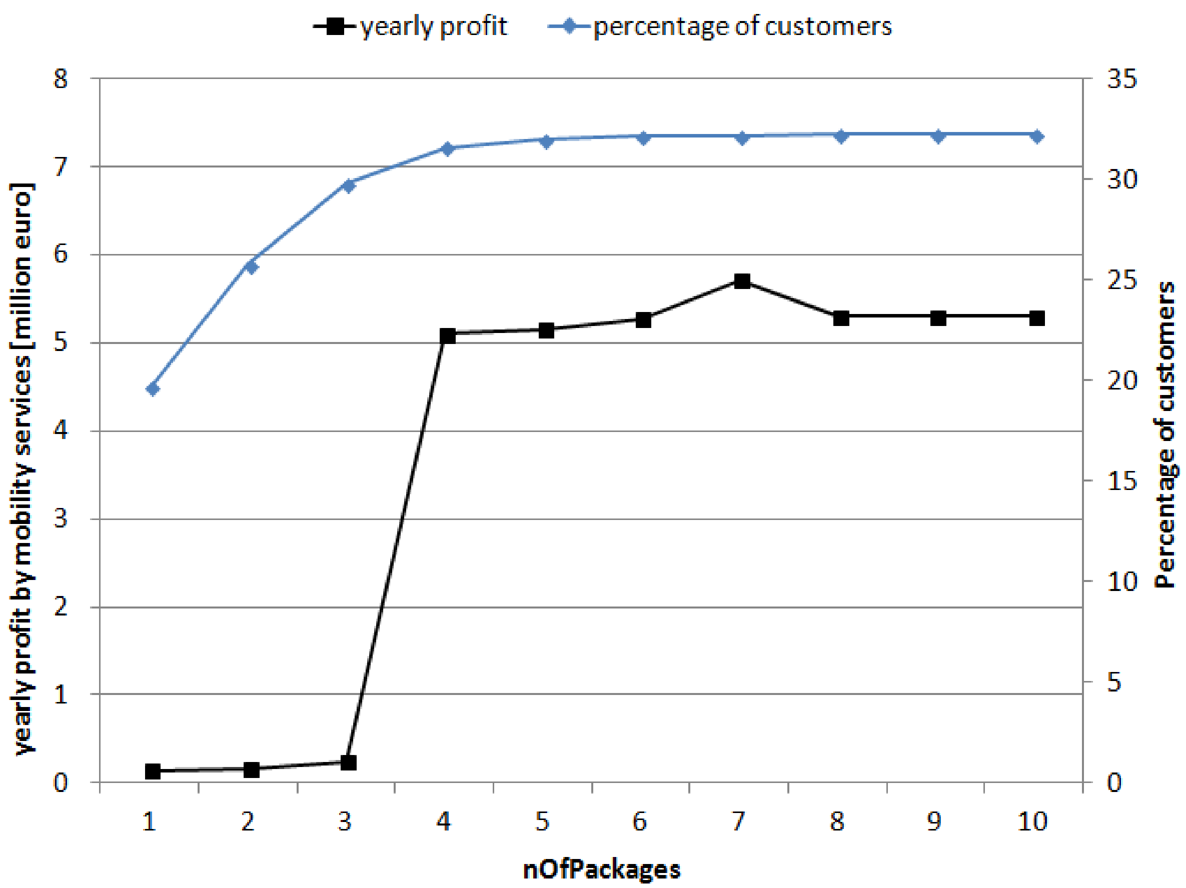

Figure 5.7: Yearly profit generated by the mobility services and percentage of travelers that become actual customers for varying number of packages offered

5.3.3 Varying both the number of sub-lists and the number of packages

Instead of keeping one of the two variables fixed, both the variables are now varied between 1 and 10, in increments of 1 up until 4 and then in increments of 2. The graphs that show the results of these simulations can be found in the appendices, more specifically from Appendix 10 to Appendix 16. A complete overview of the reaction of the percentage of travelers that become customers and the yearly profit of the MaaS provider can be found in Figure 5.8 and Figure 5.9.

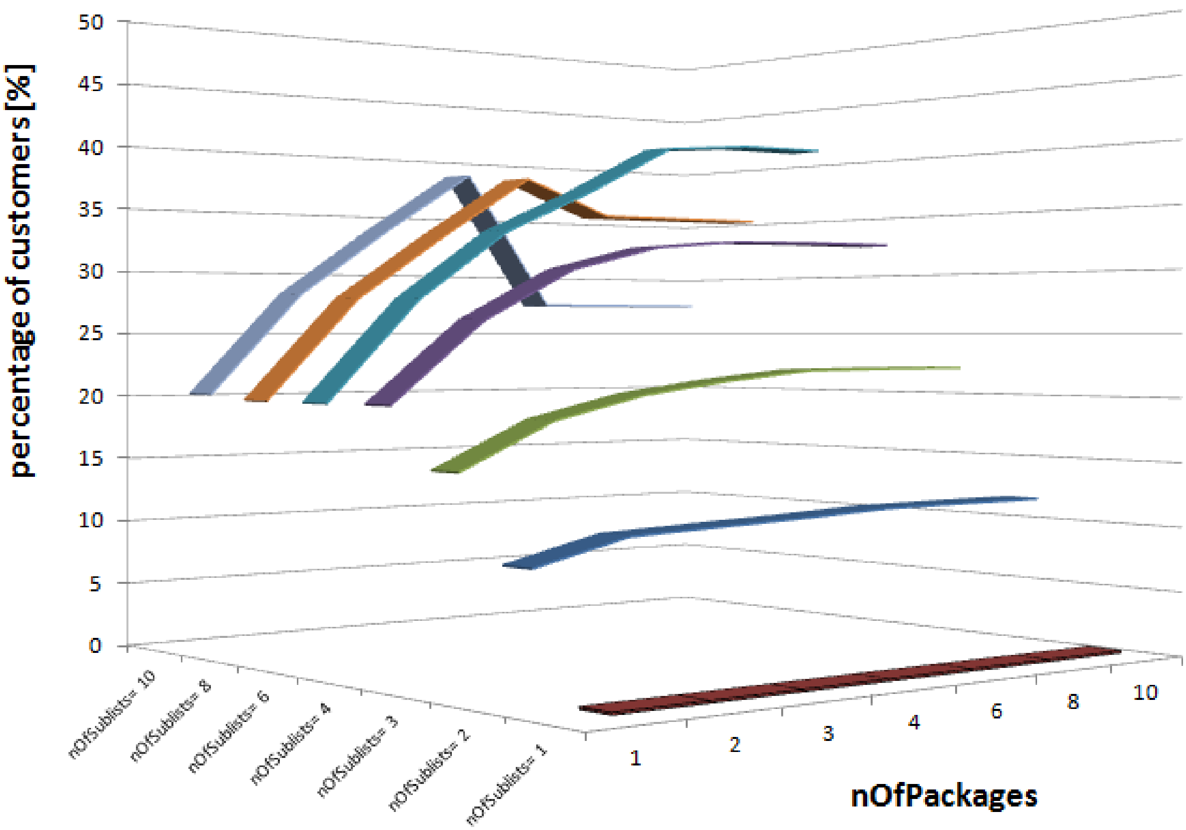

Figure 5.8: Percentage of travelers that become actual customers with varying nOfPackages and nOfSublists

The same conclusion as in Section 5.3.1 can be taken out of Figure 5.8: the percentage of travelers that become customers increases if the *nOfSublists* increases and the *nOfPackages* remains fixed. But when the number of sub-lists is 6 or more, the percentage of travelers that become customers saturates when the *nOfSublists* is lower or equal to 6. If the *nOfSublists* is set to 1, the percentage of travelers that become customer stays the same no matter how many mobility packages a MaaS provider offers. This is due to the fact that only one mobility package can be constructed if *nOfSublists* is 1.

The graphs in Figure 5.8 where the *nOfSublists* is set to 8 or 10 follow a remarkable pattern when the *nOfPackages* is higher than 4: the graph decreases. This is due to the fact that the optimal model only works with the 17 best mobility packages from the sub-optimal model if the *nOfPackages* is higher than 4 (Section 5.3.2). Because the *nOfSublists* is high, there are a lot of possible mobility packages, causing the chance that an optimal mobility package will not be included in the 17 packages that are selected by the sub-optimal model to increase. This is the reason why the graphs have this unusual pattern. In the optimal solution, the percentage of travelers that become customers will never decrease with increasing *nOfPackages*.

In general, the graph in Figure 5.8 visualizes the fact that the highest percentage of travelers that become customers can be obtained by setting the variables, *nOfSublists* and *nOfPackages* to the same value. To get the largest percentage of travelers that become customers, thus obtaining the largest market share, both the variables need to be set to 6.

Figure 5.9 shows that for almost every number of sub-lists, there comes a point where the yearly profit increases significantly. This is the point where the number of sub-lists and the number of offered packages becomes exactly the same. After this point, the yearly profit stays roughly the same for increasing number of packages offered. The big jumps in the yearly profit can be explained by the same principle that was mentioned Section 5.3.2. If the number of sub-lists becomes higher than 6, the yearly profit is significantly lower than with the other number of sub-lists. This is due to the fact that when the offered mobility packages suit the needs of the travelers very well, the travelers will use almost everything in their mobility package, hence, taking away a part of the MaaS provider's profit source.

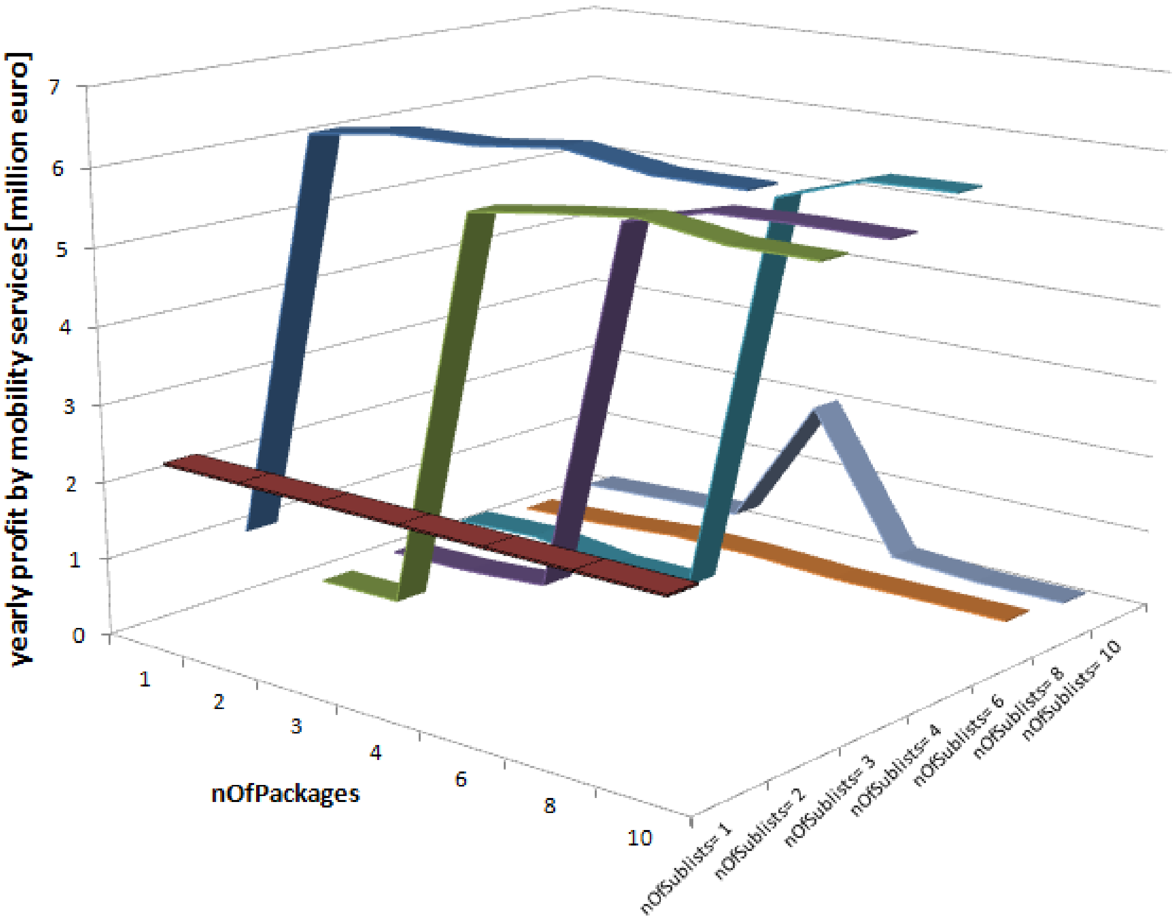

Figure 5.9: Yearly profit of a MaaS provider generated by the mobility services with varying nOfPackages and nOfSublists

5.4 Analysis of different costs and revenue of the Maas provider

When simulating the reference scenario for a population size of 100 000 travelers, the costs and revenues that are obtained then are shown in Figure 5.10. The total transportation cost, cost of the integrated payment system and the storage and data retrieval cost are three costs that are influenced by the mobility packages offered. Because these packages are constructed on the basis of the traveling needs of the population, the actual source of influence are the traveling needs of the travelers. For instance, a mobility package that only offers bike-sharing services will contribute a lot less to the total transportation cost than a mobility package that offers car-sharing services, due to the fact that the price of car-sharing kilometers is much higher than the price of bike-sharing kilometers. The same applies for the storage and retrieval cost of data, because this cost depends on the time it takes to travel. Obviously, the total travel time of the customers will also depend on the size of the customer base.

The two remaining costs that a MaaS provider encounters by offering mobility services are the development and maintenance cost of the mobile application and the website. These costs depend only on the number of customers a MaaS provider could attract with the offered mobility packages. The development and maintenance cost of this software is modeled as a fixed cost per customer.

By taking the sum of the five previous costs, the total mobility cost of a MaaS provider is found. Subtracting this cost from the revenue generated by the mobility services, gives the yearly profit that the MaaS provider makes out of the mobility services offered. As mentioned in Section 3.2.1, this revenue originates from selling mobility packages. Hence, this revenue is also influenced by the traveling needs of the population. The higher the transport services offered in the mobility packages the higher the mobility revenue will be for the MaaS provider.

Out of the tests done in the previous Sections, it became clear that both the *purchaseDiscount* and the *travelersBenefit* have an influence on the yearly profit that a MaaS provider makes. The discount received by the MaaS provider from its transport suppliers influences the total transport cost that a MaaS provider has. And the discount a MaaS provider gives to its customers influences the mobility revenue it has. Another parameter that also has an influence is the *nOfSublists*, because this parameter indirectly determines the kind of mobility packages that are formed. As mentioned above, the kind of mobility package has an influence on both the mobility cost and the revenue.

If the MaaS provider decides to also offer information services, it has an extra cost. This cost consists of the storage and retrieval cost of the data, cost to analyze the raw data and the development and maintenance cost of the website. This last cost is exactly the same as for the mobility services offered, because this is a common cost that is evenly divided over the two services offered. 90% of the data collected by the MaaS provider is used to be able to offer reports about the travel behavior of the travelers. Due to this percentage, the cost to store and retrieve the data is a lot higher than the one above. The third cost is not calculated in the implementation model, thus needs to be taken into account when decisions are taken on the basis of the cost that a MaaS provider would encounter when offering information services

```
-----------------------------------------------------------------------
                          Mobility services
-----------------------------------------------------------------------

Total transportation cost: 3.474429002E7 euro/year
Cost integrated payment system: 295326.47 euro/year
Development and maintenance cost mobile application: 8596.8 euro/year
Storage and retrieval cost data : 3.26 euro/year
Development and maintenance cost website: 318.4 euro/year

=> Cost mobility services: 3.5048535E7 euro/year

Revenue mobility services: 4.0167852E7 euro/year

Profit originating from mobility services: 5119317.0 euro/year


-----------------------------------------------------------------------
                        Information services
-----------------------------------------------------------------------
Storage and retrieval cost data : 29.33 euro/year
Development and maintenance cost website: 318.4 euro/year

=> Cost information services: 348.0 euro/year
```

Figure 5.10: Cost and revenue output of the implementation model

5.5 Conclusion

This chapter described how the implemented JAVA model was used to simulate different scenarios to find out which parameters had a significant impact on the business model. The parameters that were investigated are: the discount given to the travelers (*travelersBenefit*), the discount received from the transport suppliers (*purchaseDiscount*), the number of sub-lists per transport mode used to represent the traveling needs of the population (*nOfSublists*) and the number of mobility packages offered to the travelers (*nOfPackages*). Their impact was investigated by ranging the different parameters in a reference scenario, which consists of a population size of 100 000 travelers, a maximum statistic to represent the traveling needs of a group of travelers and a combination of a sub-optimal and optimal model to solve the optimization problem. The population size was set to 100 000 because the results stagnate from this size. Using the maximum as the statistic to represent the traveling needs of a group turned out to be the best option when aiming for maximizing the number of travelers that become customer of the MaaS provider. After multiple simulations, it was clear that the combination of the sub-optimal model and optimal, performed exactly the same as the optimal model in the framework of the tests that will still be carried out.

After the construction of the reference scenario, this scenario was used to investigate the impact of the parameters. When the *nOfSublists* increases, the percentage of travelers that become customers increases as well until the saturation point is reached. A similar observation was made for the yearly profit of the MaaS provider originating from the mobility services. This saturation point resembles the point where the mobility packages become too tailored to a single group of travelers. When *nOfPackages* varies, the percentage of travelers that become customers increases according to the number of packages offered, until this number is equal to *nOfSublists*. From then on, this percentage and the yearly profit approximately stay the same. In the yearly profit a big jump is taken from the point where the *nOfPackages* is equal to the number of sub-lists minus 1 to the point where both the variables are identical. This big jump is caused by the fact that the mobility package that is left out when the *nOfPackages* is equal to the (*nOfSublists*-1) is a package that offers a lot more kilometers than the offered packages. When this package is included by increasing the *nOfPackages,* the yearly profit will increase significantly. The highest percentage of travelers that become customers can be obtained by setting the variables, *nOfSublists* and *nOfPackages* to the same value, more specifically to 6.

The two most influential variables on the business model are the *purchaseDiscount* and the *travelersBenefit*. By varying the *purchaseDiscount* and *travelersBenefit,* the following findings were found. If the *travelersBenefit* is fixed, the yearly profit originating from the mobility services increases linearly with an increasing *purchaseDiscount*. When the *purchaseDiscount* is fixed and the *travelersBenefit* varies, the customer base grows steadily with an increasing *travelersBenefit*. The yearly profit follows the same pattern as the customer base until the *travelersBenefit* became bigger than the *purchaseDiscount*, then the yearly profit decreases. This is due to the fact that the MaaS provider has to pay more mobility costs than there is mobility revenue when the *travelersBenefit* is bigger than the *purchaseDiscount*. Finally, to get the highest yearly profit, a MaaS provider has to set its *travelersBenefit* to the same percentage as the *purchaseDiscount* it receives, unless the *purchaseDiscount* is higher than 30%, then it has to keep its *travelersBenefit* to 30%. By choosing to set the *travelersBenefit* to a lower percentage as the *purchaseDiscount,* a direct profit will be generated. This profit will be bigger than the profit that would be generated by increasing the customer base, if the *travelersBenefit* was set to the same percentage as the *purchaseDiscount*. This because the slight increase in customer base does not weigh up to the direct profit originating from the discount received. Because of this reason it is better to set the travelersBenefit to 30% if the purchaseDiscount is higher than 30%. Because the purchaseDiscount is a percentage that is given to the MaaS provider, the MaaS provider does not have a significant influence on this variable. When the MaaS provider receives no discount from its transport suppliers, the business model will never become profitable. In that case, offering information services could be the solution.

To conclude this Chapter, an analysis of the different costs and revenue of a MaaS provider was made. The cost of the MaaS provider is split into the mobility and information cost, due to this split the contribution level of each of these costs becomes clearer. Due to the low cost of offering the information services in comparison to the cost originating from offering the mobility services, it is recommended to include the information services in the business model, no matter what the *purchaseDiscount* will be.

6
Conclusions & Future work

Mobility-as-a-Service (MaaS) represents the a shift from a system focusing purely on the transportation itself to a multi-modal system that focuses heavily on the end-users and a better service level, and hence ensures convenient switching between different transportation modes. A MaaS provider offers mobility packages that combine options from different transport provider into a single mobility service, removing the hassle of planning and paying all the different transport providers separately. Customers of a MaaS provider also generate a significant amount of data about their mobility behavior. Valuable information, like travel patterns, can be extracted out of this data. Because of this reason the value of MaaS goes beyond offering smooth mobility services to customers, it also allows providing information services, targeting longer horizons and allowing to identify trends that can be used for strategic decision making. The challenge of this master dissertation was to construct a business model for a MaaS provider in the current mobility ecosystem. A MaaS ecosystem consists of a range of different stakeholders, each of whom play an important role. The MaaS provider, the travelers, the different transport providers and the data-interested institutions form the main stakeholders. The Osterwalder Canvas was used to visualize the business model. Afterwards, the costs of a MaaS provider were estimated for a MaaS provider that would be located in Flanders, Belgium. Obviously, to compensate the cost that a MaaS provider has, revenue needs to be generated. This revenue originates from both the mobility and information services offered.

These estimations were used in a Java-based model to be able to simulate the MaaS ecosystem. The goal of this simulation model was to get a clear view on the degree of importance of the two services that a MaaS provider can offer. To test how valuable this business model is, the exact group of travelers that become customer needs to be obtained, to be able to calculate the costs and revenues of the MaaS provider. Choosing the right combination of mobility packages to offer to the simulated population, was the major challenge tackled in the model. This was solved by using a mathematical optimization model: a linear programming model that obtains the mobility packages that are linked to the travelers.

The business case was evaluated by using the yearly profit of the MaaS provider originating from the mobility services and the percentage of travelers that become customers as the performance indicators during the different tests. The purpose of the tests was to find out which parameters had a significant impact on the business model. This impact was investigated by ranging these different parameters in comparison to a reference scenario. This reference scenario consists of a population size of 100 000 travelers, a maximum statistic to represent the traveling needs of a group of travelers and an optimal model, yet using a reduced number of mobility packages (selected by a sub-optimal model).

As a result of these tests, the exact influence of some parameters was found. To conclude this master dissertation, the knowledge that was acquired is used to construct some recommendations. These recommendations can be used when a MaaS provider wants to install the MaaS concept in a particular region. Afterwards, this chapter will indicate directions for future research.

6.1 Recommendations for MaaS implementation

By programming a model in JAVA and simulating well-chosen scenarios, a clear view on how to install a MaaS ecosystem was obtained. To get the best possible business model for a MaaS provider in a certain region, some recommendations can be formulated:

- The business model of the MaaS provider will depend strongly on the discount that it receives from its transport suppliers. This discount originates from buying transport services from these suppliers in bulk, which gives them the advantages of the economies of scale principle. Hence, the MaaS provider has to negotiate a deal with these transport providers that gives it the best possible purchase discount. The higher the discount the higher the yearly profit will be, because the yearly profit increases linearly with the increase in purchase discount.

- The MaaS provider can decide to set this discount it gives to the travelers to the same percentage as the discount he himself receives, which will return the largest yearly profit. This decision however focuses on short-term thinking. It would be better if the MaaS provider would take the long-term effects into account. By increasing the discount given to the travelers, the percentage of travelers that become customers will increase, and so will the MaaS provider’s market share, which in turn will generate more yearly profit in the long-term. The downfall is that the yearly profit will decrease in the short-term, because the discount given to the travelers on the original transport price is higher than the discount received on that price. The purpose of increasing the market share of the MaaS provider is to give the MaaS provider more leverage when negotiating a deal with its transport suppliers. This leverage is given due to the fact that the larger the market share, the higher the influence of the economies of scale. This will result in receiving a larger discount from the transport suppliers, increasing the yearly profit in the long-term.
  From the moment the MaaS provider receives a purchase discount of 30% or higher, it should set the discount it gives to the travelers to 30%. Then the direct profit will generate

more profit than the increase in customer base would generate in the long-term, because the customer base would not increase significantly.

- When the MaaS provider receives no discount from its transport suppliers, the business model is not profitable. In that case offering information services should be the solution. Because of the extremely low cost of the information services, incorporating the information services into the business model of the MaaS provider will generate an extra profit. The cost to store and retrieve the raw data is low. But the cost to analyze the raw data has to be kept in mind while doing research at the exact costs and revenue of this service. Because this master dissertation is not focused on the exact cost and revenue models of offering information, the assumption was made that this service is extremely profitable.
  In principle, when the MaaS provider gets a purchase discount of 5% or higher, it is capable of constructing a profitable business model without offering the information services. But it is even then recommended to include the information services because this service does not have a significant cost in comparison with the extra revenue this service could generate.

6.2 Future work

Some aspects surrounding this master dissertation have to be further investigated to get a more realistic model of the MaaS ecosystem and consequently an even more realistic business model. Two types of future work exist, on the one hand the future work on the implementation model and on the other hand the future work that looks at the bigger picture.

6.2.1 Future work on the implementation model

Potential optimizations or additions to the implementation model are the following:

- The business model and the implementation model can be further expanded by including other transportation modes, for example taxi.

- Better estimate of the purchase discount: try to contact the different transport providers that offer the transport services that will be included in a mobility package, to negotiate a deal. Hence, the exact purchase discount that the MaaS provider will get from its transport suppliers is known and can be used in the model, which makes the model more realistic.

- Instead of focusing the implementation model on a fixed transport provider per transport mode, other transport providers could be included to compare the different scenarios to each other, and even construct business cases for other countries.

- Despite the fact that the persons used in the simulations are generated according to traveling statistics found in literature, it would be even better to work with real persons. This can be done by working together with a mobility company or research center that has exact travel information of a group of persons. These traveling needs can then serve as input for the model.

- The aspect of the implementation model that requires the most improvement is the algorithm that assigns the traveling needs of a person (in kilometers) to a transport mode. This is currently done on the basis of the preference of a person. To make the model even more realistic, the process that assigns a preference to a person and the process that assigns a travel to a transport mode should be further developed.

- In the current implementation, the number of matches (number of actual customers) is used as the score a combination gets in the objective function. Instead of the number of matches, the profit that would be generated by such a combination could be used. This will result in the combination with that generates the most yearly profit instead of the combination that will convince the most travelers to become customers.

- Besides the decision process that assigns traveling needs to a transport mode, there also exists a decision process that decides if a traveler buys a certain mobility package or not. As already mentioned above, simulating a decision of a person is very difficult, thus this algorithm can be improved. Maybe a questionnaire can be drawn up and filled in by different travelers.

6.2.2 Future work on implementing a MaaS ecosystem in real-life

When installing a MaaS concept, a lot of challenges will be encountered. How exactly these challenges can be solved needs to be further investigated, but this master dissertation definitely identified some:

- The most obvious challenge that needs to be further investigated is how the cooperation between the different transport providers and the MaaS provider will evolve. Will the different transport providers react positively on this new concept or do they want to stop the MaaS provider from installing such a concept?

- A MaaS provider makes use of an integrated payment system to assure a smooth and fast mobility experience of the travelers. How such a system is implemented with all the transport suppliers of a MaaS provider needs to be further investigated, because every transport provider that wants to sells its transport services to the MaaS provider has to use this payment system in order to qualify to be a transport supplier.

- What the exact impact will be on the business models of the separate transport providers, is not yet determined. It is possible that the transport providers have to move away from a business-to-consumer model to a model that is focused on supplying transport resources to a MaaS provider. If this change will be positive or negative can differ for every transport provider.

- The big challenge about the data aspect of Maas will be the privacy of the customers. The customer will not approve to make their personal information public. A privacy policy that works for both the MaaS provider and his customers, needs to be found.

- To get the full effect of the MaaS concept, the mobility infrastructure has to be well developed. For instance, a well-developed cycling road infrastructure will give the travelers a very competitive alternative to cars. Are the governments willing to invest in such infrastructures?

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Appendices

Appendix 1: Week schedule

This appendix shows the a week schedule of a traveler that is generated by the implementation model. This is week schedule of an employed male with a age lower than 64 years old and a traveling preference of money. In the introduction of Section 4, Section 4.1 and Section 4.2 a reference to this appendix is made.

Week Schedule

	Monday [km]	Tuesday [km]	Wednesday [km]	Thursday [km]	Friday [km]	Saturday [km]	Sunday [km]
12:00 pm - 1:00 am	0	0	0	0	1	0	0
1:00 am - 2:00 am	0	0	0	0	0	0	0
2:00 am - 3:00 am	0	0	0	0	0	0	0
3:00 am - 4:00 am	0	0	0	0	0	0	0
4:00 am - 5:00 am	0	0	0	0	0	0	0
5:00 am - 6:00 am	0	0	0	0	0	0	0
6:00 am - 7:00 am	0	18	18	0	18	0	0
7:00 am - 8:00 am	18	28	0	18	0	0	0
8:00 am - 9:00 am	0	0	3	0	5	0	0
9:00 am - 10:00 am	1	0	0	0	0	0	0
10:00 am - 11:00 am	0	0	0	0	0	0	0
11:00 am - 12:00 am	0	0	0	0	0	0	0
12:00 am - 1:00 pm	0	0	0	2	0	0	0
1:00 pm - 2:00 pm	0	5	0	0	0	4	0
2:00 pm - 3:00 pm	1	19	0	0	0	0	3
3:00 pm - 4:00 pm	0	0	0	0	3	5	0
4:00 pm - 5:00 pm	18	0	25	0	0	29	0
5:00 pm - 6:00 pm	0	18	0	18	0	0	36
6:00 pm - 7:00 pm	0	0	18	0	18	0	0
7:00 pm - 8:00 pm	0	0	0	0	0	0	19
8:00 pm - 9:00 pm	0	0	2	0	0	0	0
9:00 pm - 10:00 pm	0	0	0	1	0	0	0
10:00 pm - 11:00 pm	0	0	0	0	0	0	0
11:00 pm - 12:00 pm	0	0	0	0	0	0	0

Person 6

Category:	under 64
Gender:	male
Work status:	employed
Preference:	money

Appendix 1: Week schedule of person 6 that is generated by the implementation model

Appendix 2: Mobility package

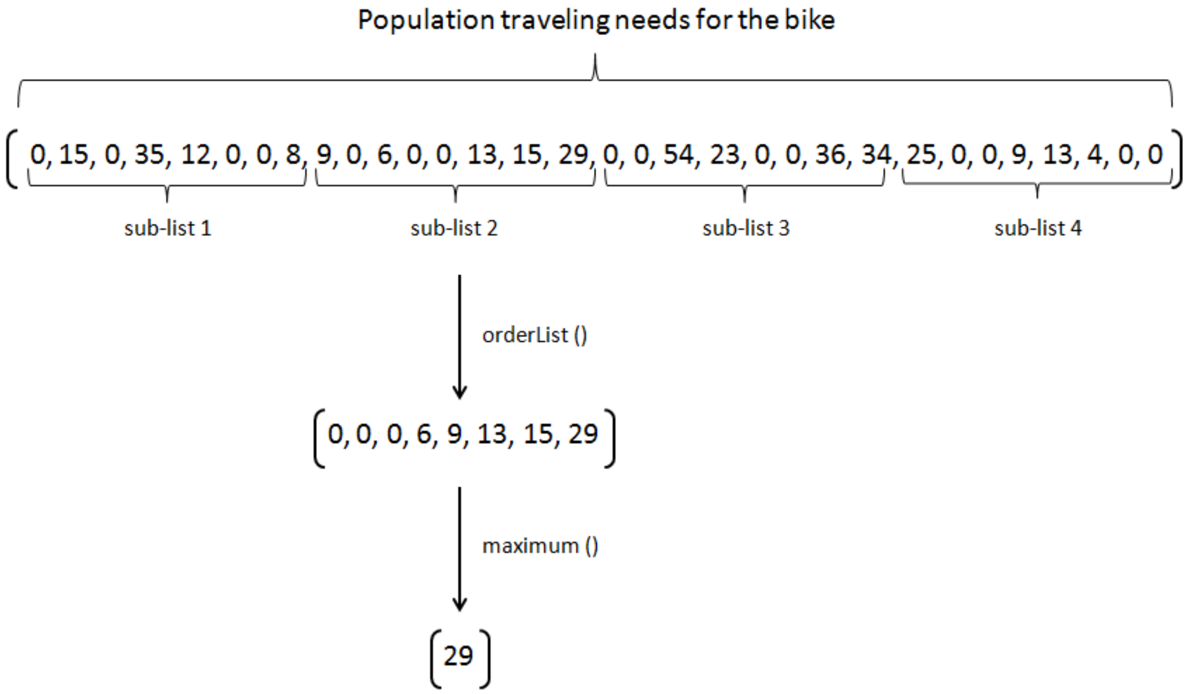
This appendix shows a mobility packages that a MaaS provider would offer to the travelers to try to convince them to become actual customers. This packages is a output from the implementation model. In the introduction of Section 4 and in Section 4.2 a reference to this appendix is made.

Mobility package: Package 3	
Kilometers of Bike	38
Kilometers of Bus	68
Kilometers of Train	0
Kilometers of Car	159

Appendix 2: Mobility package generated by the model (transport supplies for a week)

Appendix 3: Explanation of algorithm that construct possible mobility packages

Here the different steps taken in the algorithm that constructs the possible mobility packages is shown. More specifically, how the number of sub-lists and the statistic are used in this process. The final number of kilometer that is obtained is used to construct different mobility packages. In Section 4.2.2, Section 5.1.2 and Section 5.3 a reference to this appendix is made.



Appendix 3: Explanation of how the sub-lists and statistics are used in the model

Appendix 4: Linear model used by the optimal model

The actual optimization model for the optimal model constructed by the GUROBI solver is showed in this appendix. This is the result for a simulation with the following parameter values: nOfPersons = 100 000, nOfSublists = 4, nOfPackages = 4, purchaseDiscount = 15%, travelersBenefit = 15%, Statistic = maximum). Section 4.2.3 refers to this appendix.

```
Minimize
  - 53 M_0 - 53 M_1 - 53 M_2 - 247 M_3 - 53 M_4 - 57 M_5 - 54 M_6 - 53 M_7
   - 56 M_8 - 151 M_9 - 54 M_10 - 59 M_11 - 53 M_12 - 53 M_13 - 54 M_14
   - 124 M_15 - 53 M_16 - 60 M_17 - 58 M_18 - 54 M_19 - 54 M_20 - 169 M_21
   - 53 M_22 - 64 M_23 - 58 M_24 - 53 M_25 - 57 M_26 - 131 M_27 - 54 M_28
   - 64 M_29 - 56 M_30 - 53 M_31 - 55 M_32 - 73 M_33 - 53 M_34 - 64 M_35
   - 58 M_36 - 53 M_37 - 56 M_38 - 106 M_39 - 53 M_40 - 68 M_41 - 57 M_42
   - 53 M_43 - 58 M_44 - 53 M_45 - 53 M_46 - 67 M_47 - 53 M_48 - 53 M_49
   - ...
   - 9 M_316225 - 21 M_316226 - 21 M_316227 - 21 M_316228 - 9 M_316229
   - 9 M_316230 - 9 M_316231 - 21 M_316232 - 21 M_316233 - 21 M_316234
   - 9 M_316235 - 21 M_316236 - 21 M_316237 - 21 M_316238 - 8 M_316240
   - 8 M_316241 - 21 M_316242 - 21 M_316243 - 21 M_316244 - 8 M_316245
   - 21 M_316246 - 21 M_316247 - 21 M_316248 - 8 M_316249 - 21 M_316250
Subject To
 _: M_0 + M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 + M_8 + M_9 + M_10 + M_11
   + M_12 + M_13 + M_14 + M_15 + M_16 + M_17 + M_18 + M_19 + M_20 + M_21
   + M_22 + M_23 + M_24 + M_25 + M_26 + M_27 + M_28 + M_29 + M_30 + M_31
   + M_32 + M_33 + M_34 + M_35 + M_36 + M_37 + M_38 + M_39 + M_40 + M_41
   + M_42 + M_43 + M_44 + M_45 + M_46 + M_47 + M_48 + M_49 +
   + ...
   + M_316225 + M_316226 + M_316227 + M_316228 + M_316229 + M_316230
   + M_316231 + M_316232 + M_316233 + M_316234 + M_316235 + M_316236
   + M_316237 + M_316238 + M_316239 + M_316240 + M_316241 + M_316242
   + M_316243 + M_316244 + M_316245 + M_316246 + M_316247 + M_316248
   + M_316249 + M_316250 = 1
Bounds
Binaries
 M_0 M_1 M_2 M_3 M_4 M_5 M_6 M_7 M_8 M_9 M_10 M_11 M_12 M_13 M_14 M_15 M_16
 M_17 M_18 M_19 M_20 M_21 M_22 M_23 M_24 M_25 M_26 M_27 M_28 M_29 M_30 M_31
 M_32 M_33 M_34 M_35 M_36 M_37 M_38 M_39 M_40 M_41 M_42 M_43 M_44 M_45 M_46
 M_47 M_48 M_49
 ...
 M_316225 M_316226 M_316227 M_316228 M_316229 M_316230 M_316231 M_316232
 M_316233 M_316234 M_316235 M_316236 M_316237 M_316238 M_316239 M_316240
 M_316241 M_316242 M_316243 M_316244 M_316245 M_316246 M_316247 M_316248
 M_316249 M_316250
End
```

Appendix 4: Gurobi model (nOfPersons=1000, nOfSublists=4, nOfPackages=4, purchaseDiscount=15%, travelersBenefit=15%, Statistic=maximum, Optimal model used)

Appendix 5: Linear model used by the sub-optimal model

The actual optimization model for the sub-optimal model (nOfMatches) constructed by the GUROBI solver is showed in this appendix. This is the result for a simulation with the following parameter values: nOfPersons = 100 000, nOfSublists = 4, nOfPackages = 4, purchaseDiscount = 15%, travelersBenefit = 15%, Statistic = maximum). Section 4.2.4 refers to this appendix.

```
Minimize
  - 53 M_1 - 4 M_2 - 2 M_5 - 204 M_6 - 43 M_7 - 11 M_8 - 2 M_9 - 7 M_11
   - 104 M_12 - M_13 - 11 M_14 - 8 M_17 - 60 M_18 - 48 M_19 - 13 M_20
   - 6 M_23 - 124 M_24 - 28 M_25 - 20 M_26 - M_27 - 11 M_29 - 85 M_30
   - 18 M_32 - 11 M_35 - 9 M_36 - 20 M_38 - 4 M_39 - 9 M_41 - 11 M_42
   - 25 M_44 - 3 M_45 - 14 M_47 - 23 M_50 - 12 M_53
Subject To
 _: M_0 + M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 + M_8 + M_9 + M_10 + M_11
   + M_12 + M_13 + M_14 + M_15 + M_16 + M_17 + M_18 + M_19 + M_20 + M_21
   + M_22 + M_23 + M_24 + M_25 + M_26 + M_27 + M_28 + M_29 + M_30 + M_31
   + M_32 + M_33 + M_34 + M_35 + M_36 + M_37 + M_38 + M_39 + M_40 + M_41
   + M_42 + M_43 + M_44 + M_45 + M_46 + M_47 + M_48 + M_49 + M_50 + M_51
   + M_52 + M_53 = 4
Bounds
Binaries
 M_0 M_1 M_2 M_3 M_4 M_5 M_6 M_7 M_8 M_9 M_10 M_11 M_12 M_13 M_14 M_15 M_16
 M_17 M_18 M_19 M_20 M_21 M_22 M_23 M_24 M_25 M_26 M_27 M_28 M_29 M_30 M_31
 M_32 M_33 M_34 M_35 M_36 M_37 M_38 M_39 M_40 M_41 M_42 M_43 M_44 M_45 M_46
 M_47 M_48 M_49 M_50 M_51 M_52 M_53
End
```

Appendix 5: Gurobi model (nOfPersons=1000, nOfSublists=4, nOfPackages=4, purchaseDiscount=15%, travelersBenefit=15%, Statistic=maximum, Sub-optimal model used, weights=nOfMatches)

Appendix 6: GUROBI output for sub-optimal model

This appendix shows the output that is generated by the GUROBI solver when the linear model of appendix 5 was optimized. Section 4.2.4 refers to this appendix.

```
# Objective value = -517
M_0 0
M_1 0
M_2 0
M_3 0
M_4 0
M_5 0
M_6 1
M_7 0
M_8 0
M_9 0
M_10 0
M_11 0
M_12 1
M_13 0
M_14 0
M_15 0
M_16 0
M_17 0
M_18 0
M_19 0
M_20 0
M_21 0
M_22 0
M_23 0
M_24 1
M_25 0
M_26 0
M_27 0
M_28 0
M_29 0
M_30 1
M_31 0
M_32 0
M_33 0
M_34 0
M_35 0
M_36 0
M_37 0
M_38 0
M_39 0
M_40 0
M_41 0
M_42 0
M_43 0
M_44 0
M_45 0
M_46 0
M_47 0
M_48 0
M_49 0
M_50 0
M_51 0
M_52 0
M_53 0
```

Appendix 6: Gurobi result (nOfPersons=1000, nOfSublists=4, nOfPackages=4, purchaseDiscount=15%, travelersBenefit=15%, Statistic=maximum, Sub-optimal model used, weights=nOfMatches)

Appendix 7: Output implementation model

This appendix shows the output that is generated by the implementation model. Especially the number of matches (customers) and the yearly profit are important. This appendix is referred to in Section 5.1.1.

Number of persons in market	100000
Number of matches	31847
Percentage [%]	31,847
Number of sub-lists	4
Number of offered packages	4
Percentage of customers that bought mobility package 1:	4,03
Percentage of customers that bought mobility package 2:	19,817
Percentage of customers that bought mobility package 3:	6,159
Percentage of customers that bought mobility package 4:	1,841
Discount percentage (economy of scale)	0,85
Travelers benefit percentage	0,85
Allowed percentage of offered kilometers	110
Percentage of cost difference a customer is willing to pay for	90
Statistic used to simulate needs of travelers in a sub-list:	maximum
Mathematical model used:	SUB OPTIMAL (Combination of both)
Function used to attach weight to variables:	Amount of matches
Calculation time [minutes]:	286,0668333
Yearly cost mobility services [euro] :	35559431
Yearly revenue mobility services [euro] :	40754325
Yearly profit mobility services [euro] :	5194894
Yearly cost information services (not included: analyzing cost) [euro] :	321

Appendix 7: Output generated by the model (sub-optimal model combined with optimal model)

Appendix 8: Three mobility packages that are offered (nOfPackages = 3)

The three mobility packages that are chosen by the optimization model to offer to the travelers are showed in this appendix. This appendix is referred to in Section 5.3.2.

Mobility package: Package 0	
Kilometers of Bike	0
Kilometers of Bus	0
Kilometers of Train	0
Kilometers of Car	41

Mobility package: Package 1	
Kilometers of Bike	0
Kilometers of Bus	40
Kilometers of Train	0
Kilometers of Car	0

Mobility package: Package 2	
Kilometers of Bike	24
Kilometers of Bus	0
Kilometers of Train	0
Kilometers of Car	0

Appendix 8: Mobility packages offered when nOfPackages is set to 3 (reference scenario)

Appendix 9: Four mobility packages that are offered (nOfPackages = 4)

The four mobility packages that are chosen by the optimization model to offer to the travelers are showed in this appendix. This appendix is referred to in Section 5.3.2.

Mobility package: Package 0	
Kilometers of Bike	0
Kilometers of Bus	0
Kilometers of Train	0
Kilometers of Car	42

Mobility package: Package 1	
Kilometers of Bike	0
Kilometers of Bus	40
Kilometers of Train	0
Kilometers of Car	0

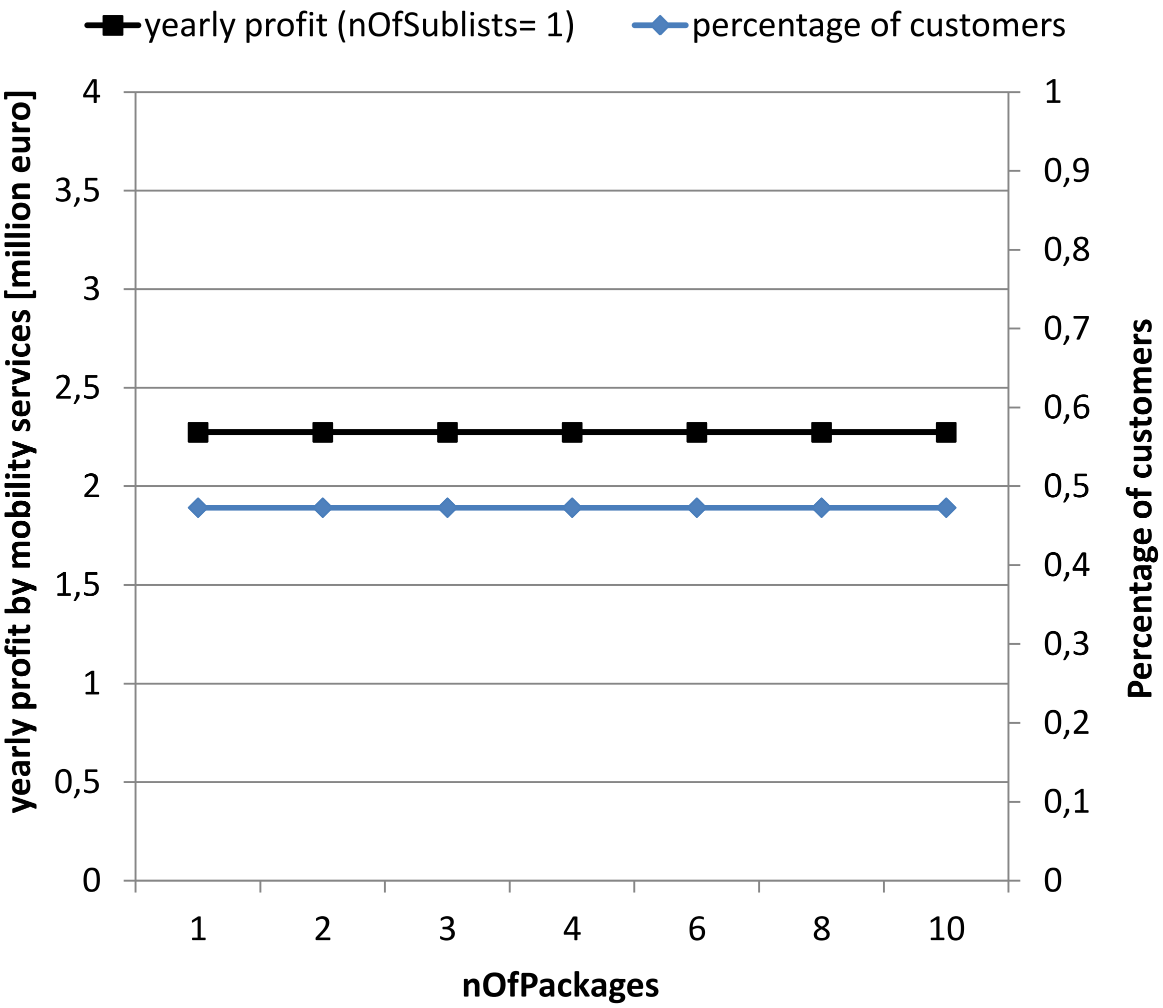
Mobility package: Package 2	
Kilometers of Bike	24
Kilometers of Bus	0
Kilometers of Train	0
Kilometers of Car	0

Mobility package: Package 3	
Kilometers of Bike	138
Kilometers of Bus	40
Kilometers of Train	0
Kilometers of Car	1050

Appendix 9: Mobility packages offered when nOfPackages is set to 4 (reference scenario)

Appendix 10: Results with varying *nOfPackages* and *nOfSublists* set to 1

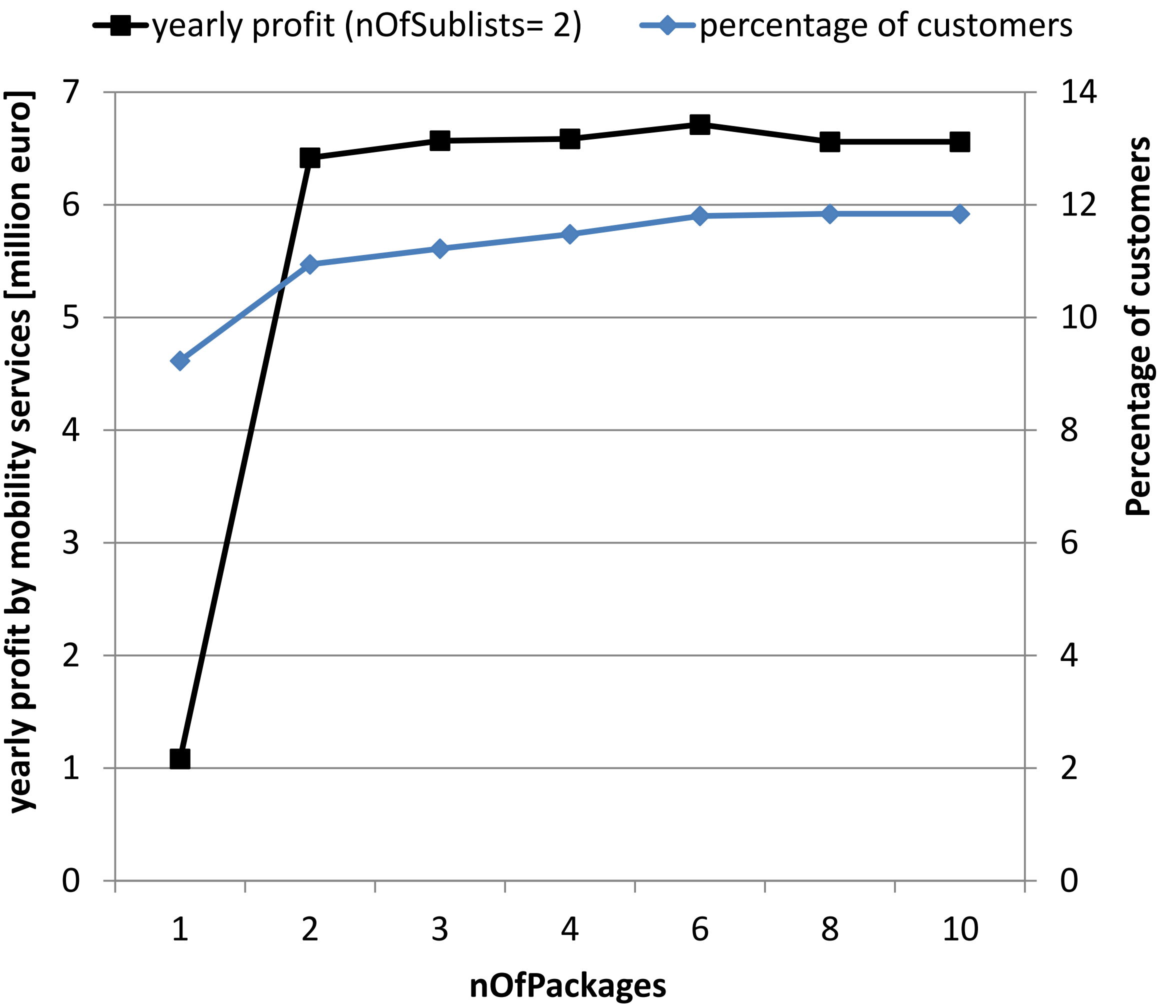
This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 1. This appendix is referred to in Section 5.3.3.



Appendix 10: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 1

Appendix 11: Results with varying *nOfPackages* and *nOfSublists* set to 2

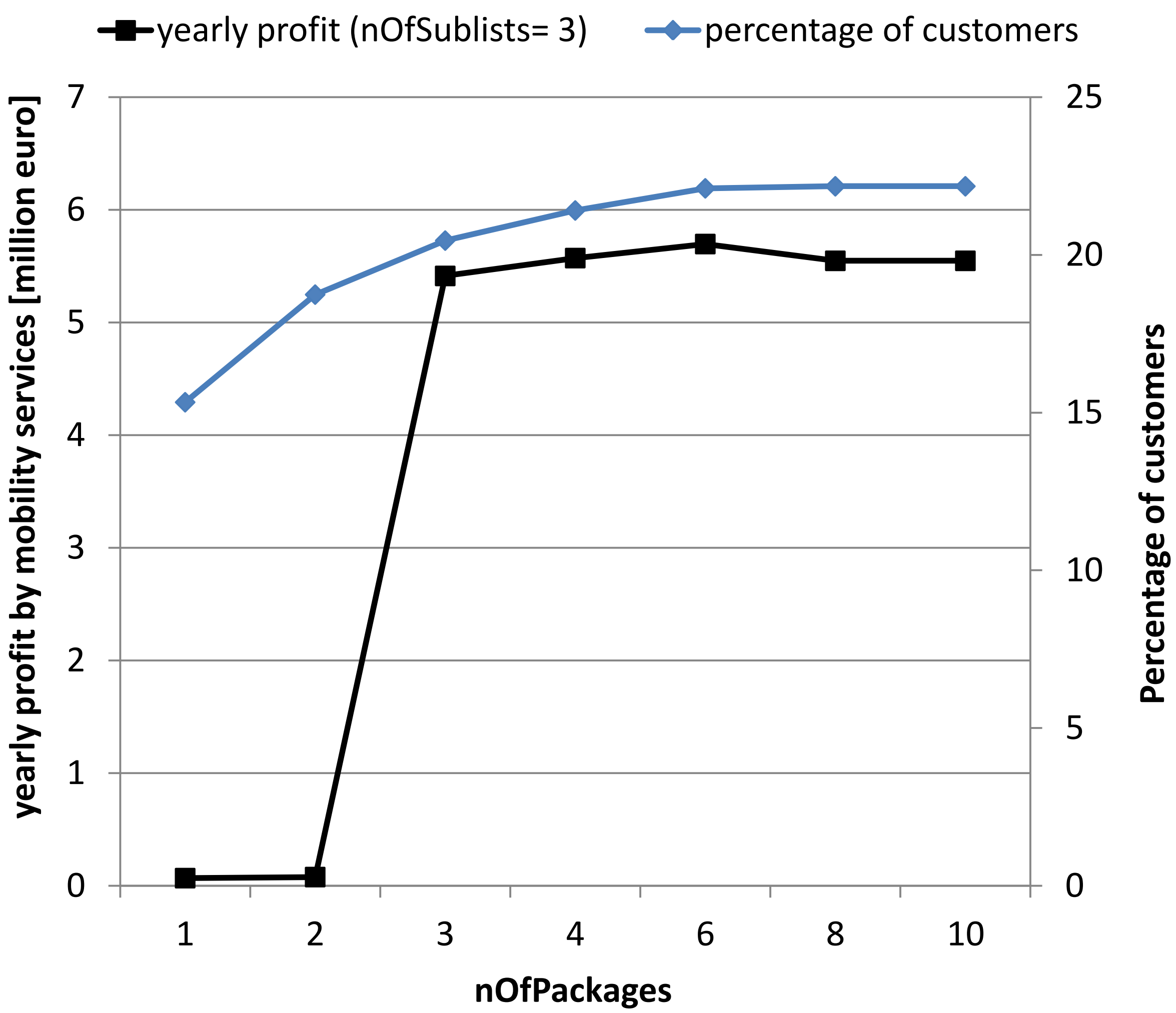
This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 2. This appendix is referred to in Section 5.3.3.



Appendix 11: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 2

Appendix 12: Results with varying *nOfPackages* and *nOfSublists* set to 3

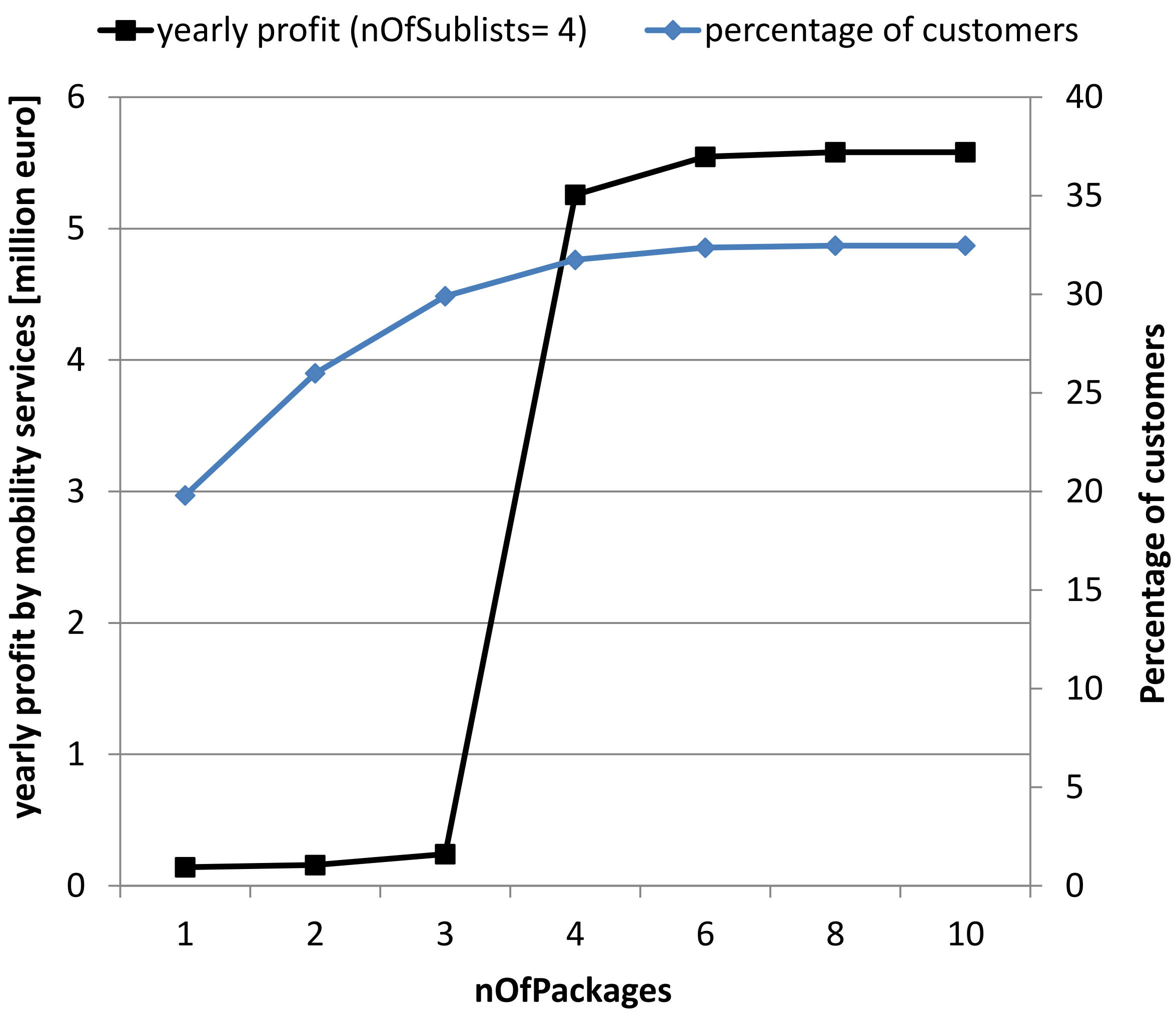
This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 3. This appendix is referred to in Section 5.3.3.



Appendix 12: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 3

Appendix 13: Results with varying *nOfPackages* and *nOfSublists* set to 4

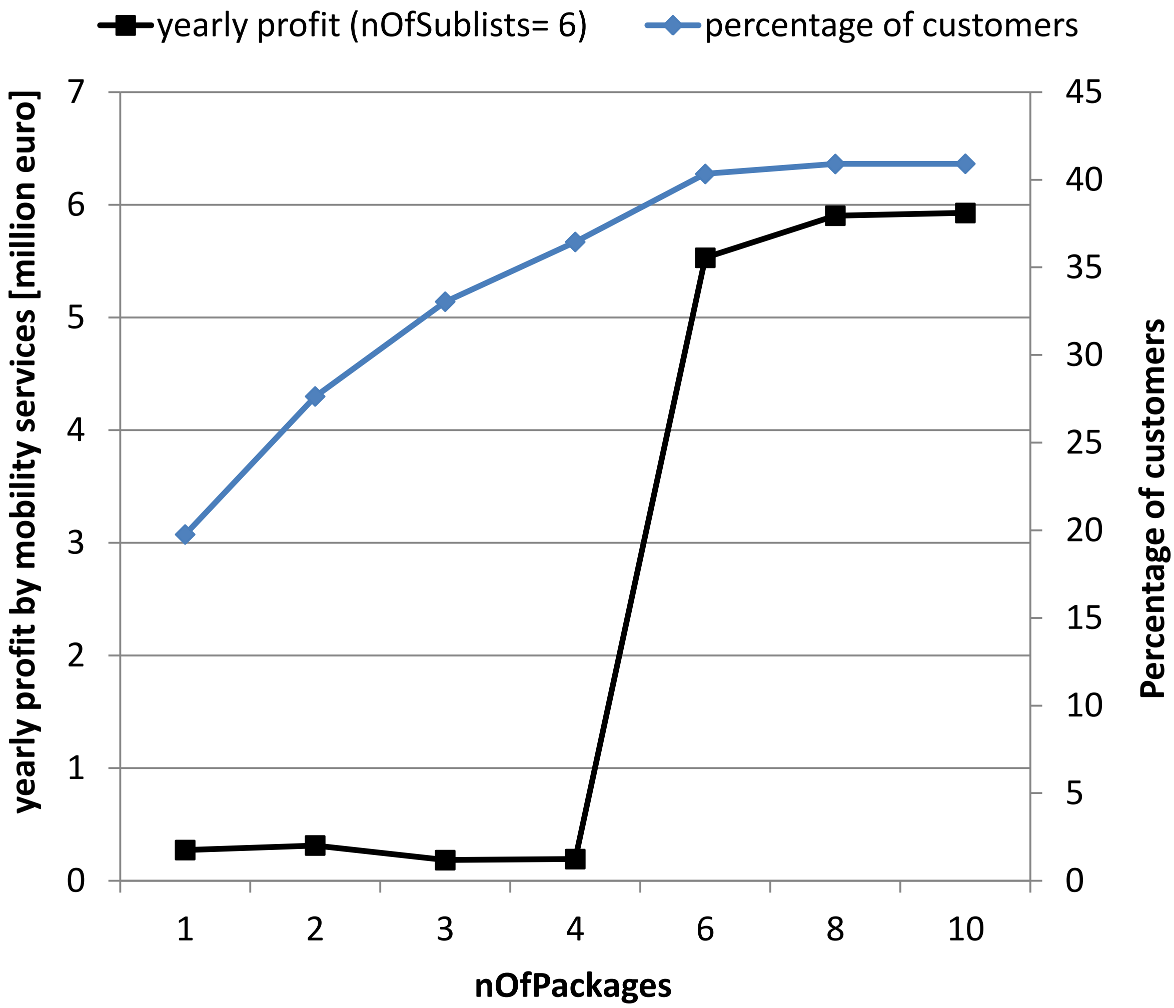
This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 4. This appendix is referred to in Section 5.3.3.



Appendix 13: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 4

Appendix 14: Results with varying *nOfPackages* and *nOfSublists* set to 6

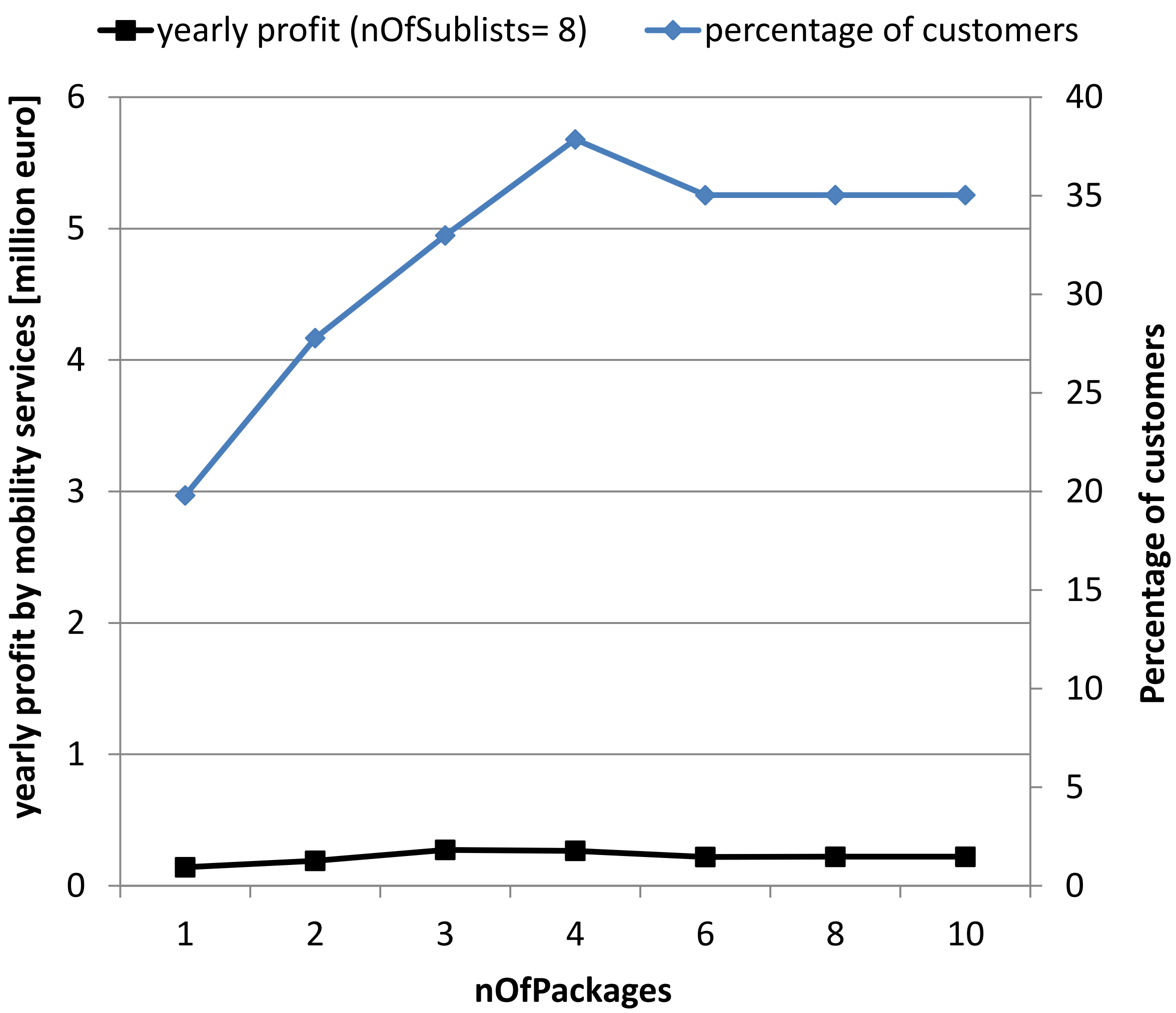
This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 6. This appendix is referred to in Section 5.3.3.



Appendix 14: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 6

Appendix 15: Results with varying *nOfPackages* and *nOfSublists* set to 8

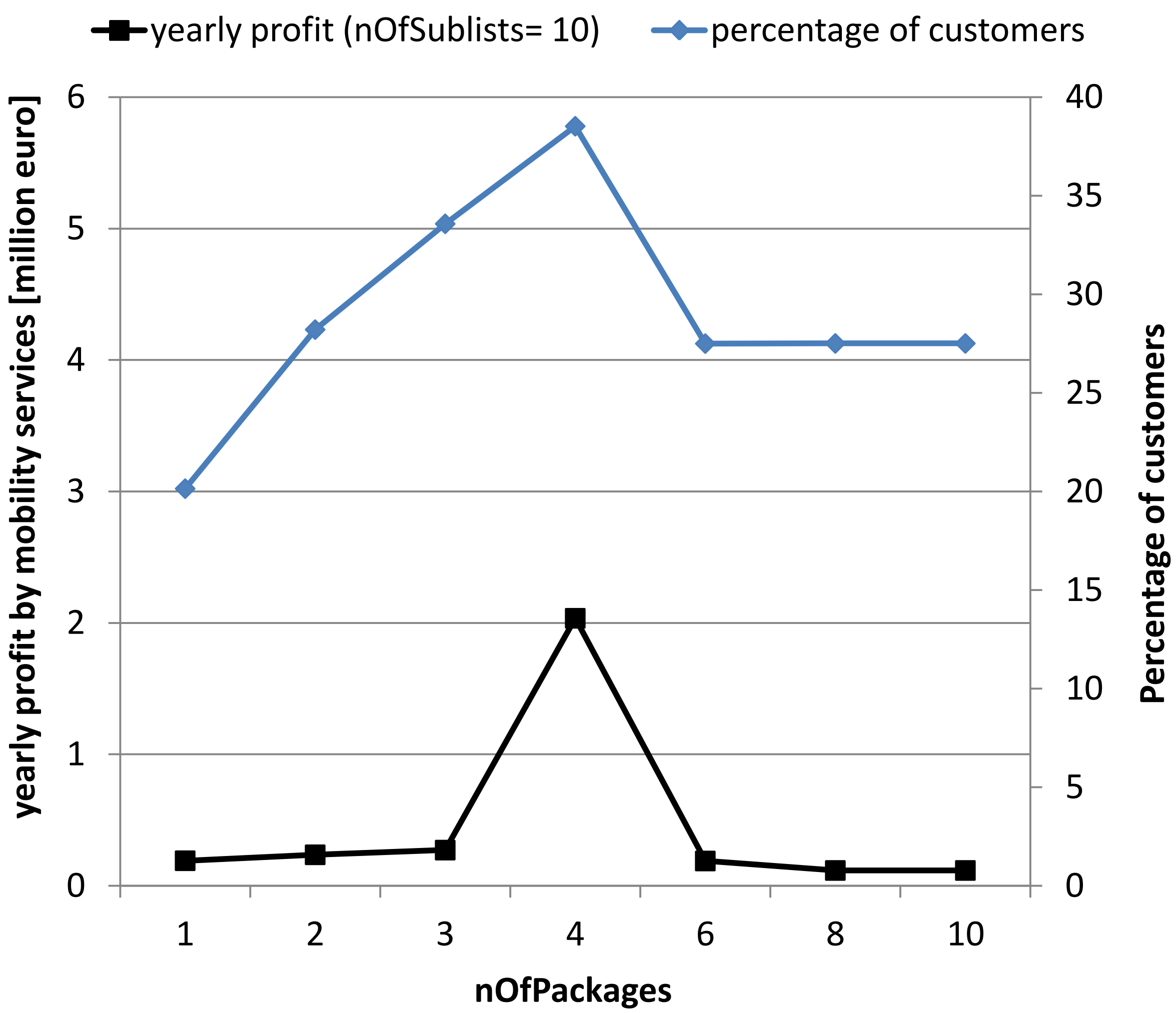
This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 8. This appendix is referred to in Section 5.3.3.



Appendix 15: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 8

Appendix 16: Results with varying *nOfPackages* and *nOfSublists* set to 10

This appendix shows the yearly profit generated by the mobility services and the percentage of travelers that become customers when the number of packages that the MaaS provider offers is varied from 1 to 10. This simulation was done with the reference scenario and the *nOfSublists* set to 10. This appendix is referred to in Section 5.3.3.



Appendix 16: Yearly profit generated by mobility services and percentage of travelers that become customers when the nOfPackages is varied and the nOfSublists is set to 10

Appendix 17: JAVA Code implementation

The code of the implementation model is included in the ZIP file that was handed in alongside this thesis book.