FACULTY OF ENGINEERING
AND ARCHITECTURE

Techno-economic analysis of micro-mobility providers: derivation of viability conditions

Anthony Demeyere
Student number: 01508836

Supervisors: Prof. dr. ir. Sofie Verbrugge, Prof. dr. ir. Didier Colle
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Master's dissertation submitted in order to obtain the academic degree of
Master of Science in Industrial Engineering and Operations Research

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Preface

This master dissertation is the final work and effort taken to obtain the degree of Master of Science in Industrial Engineering and Operation Research. It also means the end of my time as a student. Enrolling in this master has definitely opened doors for the future. Finishing this thesis would not have been possible without the help of several people.

I would like to thank my promotors, prof. dr. ir. Sofie Verbrugge and prof. dr. ir. Didier Colle, for granting me this topic. I got in touch with the field of techno-economics through the Engineering Economy course, from which I gained a growing interest in economics. Thank you for the opportunity.

Secondly, I would like to thank my supervisor Timo latruwe, who gave guidance throughout the entire process of this work. He was there to answer all my questions, gave critical remarks and passed on his knowledge in the field of techno-economics. Thank you for making this work better by using your business insights and reviewing the structure of this thesis. I wish you all the best for the future.

Finally, my friends and family should not be forgotten. I would like to thank my friends for the fun moments during our college period. It was a pleasure studying and hanging around with you in Ghent and I hope this will continue for life. A big thank you to my family and girlfriend as well for the unconditional support.

Anthony Demeyere, May 2020

Permission for usage

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Summary

The mobility landscape is in a disruptive mood. A popular and rather new concept in the sector is Mobility-as-a-Service (MaaS). Under this concept, there is the rise of new Mobility Service Providers (MSPs), such as bike sharing, moped sharing or e-scooter providers that keep innovating their fleets. The aim of this project is to perform a techno-economic analysis of current micro-mobility providers, more specifically hub-centric bike sharing and free-floating e-scooter providers. This is done primarily based on their cost structures. The construction of dynamic cost models allows to create different scenarios where parameters can be varied and from which viability conditions are derived. These conditions are in the form of scale requirements, average demand needed and price setting. Considering the bike sharing system, a positive scale effect is observed, but viability can only be assured at current pricing schemes if demand raises significantly. Free-floating e-scooters show a high potential to become viable, because the uptake is already high. The expected improvements in hardware and life expectancy of the vehicles are key drivers in making the business sustainable. On the operational aspect, charging by performing battery swaps can lower the costs significantly.

Keywords

MaaS, sharing economy, cost modelling, techno-economic, micro-mobility

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***Abstract*: The mobility landscape is in a disruptive mood. A popular and rather new concept in the sector is Mobility-as-a-Service (MaaS). Under this concept, there is the rise of new Mobility Service Providers (MSPs), such as bike sharing, moped sharing or e-scooter providers that keep innovating their fleets. The aim of this project is to perform a techno-economic analysis of current micro-mobility providers, more specifically hub-centric bike sharing and free-floating e-scooter providers. This is done primarily based on their cost structures. The construction of dynamic cost models allows to create different scenarios where parameters can be varied and from which viability conditions are derived. These conditions are in the form of scale requirements, average demand needed and price setting. Considering the bike sharing system, a positive scale effect is observed, but viability can only be assured at current pricing schemes if demand raises significantly. Free-floating e-scooters show a high potential to become viable, because the uptake is already high. The expected improvements in hardware and life expectancy of the vehicles are key drivers in making the business sustainable. On the operational aspect, charging by performing battery swaps can lower the costs significantly.**

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I. INTRODUCTION

The mobility landscape looks very disaggregated by the introduction of innovating types of transport. Telecommunication technology has enabled the rise of new models for ad-hoc mobility and payment. Investments in new mobility start-ups have increased significantly. Since 2010, investors have poured $220 billion into more than 1.100 companies across ten technology clusters, among them battery improvement, e-hailing, charging, AV software and connectivity [1].

These developments have contributed to the new concept of Mobility-as-a-Service (Maas). In this concept, transportation services are offered to customers for shared use, compared to the traditional view of needing to have ownership of several transportation means. On one side of the value network, mobility providers, such as shared bicycle operators, shared car operators, public transport providers, and others are expanding their offers, while on the other, MaaS providers are integrating different modes of transport and offering seamless mobility to end-customers.

This paper will focus on the side of the mobility providers, being the suppliers of the transportation means. Besides the more traditional mobility options such as public transport

(PT), taxi-like services and other, there is the rise of new Mobility Service Providers (MSPs), such as shared bike, shared moped and shared e-scooter operators that keep innovating their fleets under the concept of MaaS.

McKinsey [2] reported in December 2019 that the market potential across China, United States and China could reach $ 300 to $ 500 billion by 2030. Micro-mobility companies increased their investments by a factor of more than five from 2014 to 2018. Total investments now significantly exceed $1 billion already, with an average investment of about $100 million per transaction in 2018 [1]. However, currently it is far from sure whether these new MSPs add significant value to the mobility ecosystem and if they are or could ever be profitable. It seems that lots of small and larger initiatives are driven by an ambition to attain a first-mover advantage, while probably being loss-making. In 2018 one of China’s largest bike sharing start-ups Ofo went from raising more than 1 billion dollars to being on the verge of bankruptcy in only four years [3]. For the growingly popular shared e-scooters the figures are not bright either. Scooter company Lime is laying off about 14% of its workforce and shuttering operations in 12 markets as it seeks to become profitable. After two years of explosive growth, scooter companies have entered a new phase, namely survival of the fittest in a capital-intensive, money-losing industry [4].

This paper investigates operational business models of micro-mobility providers and derive minimum financial viability conditions. More specifically, the hub-centric bike sharing and free-floating e-scooter providers will serve as use case, because of their popularity and innovative character. One of the first questions that will be answered is which levers or parameters really drive the value or costs of mobility providers. Based on this knowledge, it will be possible to discover and derive the conditions under which providers could be viable in specific scenarios. Viability conditions will be in the form of average demand needed, break-even price setting or minimum scale to operate at. On the industry level, important questions are whether specific systems are scalable enough or if multiple competitors can coexist within the same micro-market.

Section II starts with giving more background on the considered micro-mobility providers and their operational aspects. In section III, the methodology for assessing micro-mobility providers will be explained. Starting from the dynamic cost model, a scenario analysis will lead to the derivation of several viability conditions. The methodology will be applied to derive the results for both hub-centric bike sharing and free-floating e-scooter providers respectively in sections IV and V.

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II. Background on Micro-Mobility Providers

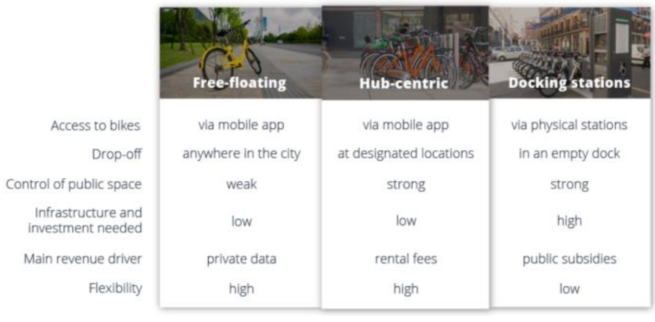
Micro-mobility providers can be classified by their vehicle type. They are transportation means that are smaller than a car and typically mechanically or electrically driven. Belonging to this category are (e-)bikes, e-scooters, mopeds, etc. Based on the available data and knowledge about the systems it was opted to evaluate hub-centric bike sharing and free-floating e-scooter providers. These MSPs are on a rise and gaining more and more attraction on the streets. Important operational aspects with a major impact on the total cost of the system are relocation for the bike-sharing providers and charging for the e-scooter providers. These two aspects are briefly discussed in this section as well.

A. *Hub-centric bike sharing providers*

A bike sharing system or scheme is a service where bicycles are offered on the streets for shared use between individuals. Usually a price or fee per short period is paid to unlock the bikes. The schemes have evolved over time by the evolution of different technologies such as GPS (Global Positioning System) and more recently IoT (Internet of Things) devices. The division is made between three operational models being station-based, free-floating or hub-centric models.

Station-based systems make use of docks or stations where bicycles are physically locked onto when not in use. Customers can rent the bikes typically by making use of a smart card at a kiosk that unlocks the bike. In the free-floating model one can leave the bike anywhere in the city at the end of a ride. Local regulations can forbid to park in certain locations such as on pavements.

The hub-centric model combines the best of both previous options. Bicycles can be found and dropped off at designated locations with a limited capacity. This way public order is retained while there is no need for the high capital investments for placing stations in the case of non-electric bikes. Some other differences between the three options are shown in Figure 1.



	Free-floating	Hub-centric	Docking stations
Access to bikes	via mobile app	via mobile app	via physical stations
Drop-off	anywhere in the city	at designated locations	in an empty dock
Control of public space	weak	strong	strong
Infrastructure and investment needed	low	low	high
Main revenue driver	private data	rental fees	public subsidies
Flexibility	high	high	low

Figure 1: Classification of bike sharing systems [5]

One of the most important and complex operations that a mobility provider encounters, is the relocation of an unbalanced vehicle sharing system. These are incurred by one-way trips, originating from one station and ending the trip in another. For example, on a sunny day in a coastal city, in the progress of the day more and more trips will be taken to the beach, resulting in occupied stations at the beach and an under-capacity in the city centre. This will result in a lower usage rate in those places and less revenue. This problem is solved by actively rebalancing vehicles from one place to another.

There exist multiple strategies to perform relocation. First of all, there is the user-based or operator-based division [6]. User-based relocation is done by giving incentives to users in the form of discounts to return the bicycle to a favourable position. Secondly, there is the difference between static or dynamic rebalancing. For static rebalancing, the relocations are performed on fixed moments, for example during the night [7], [8]. Dynamic rebalancing is done during the day by analysing stochastic demand patterns and needs [9]–[11]. In both cases, relocation vehicles depart from warehouses and perform a pick-up and delivery tour to relocate the bicycles. In this work, the static operator-based relocation will be modelled.

B. *Free-floating e-scooter providers*

E-scooters are a rather new means of transportation under the electrically driven shared mobility options. It was introduced and pioneered in 2018 by providers Lime and Bird in the U.S. [12] It is an electrically driven device, where people need to stand up and accelerate by means of turning a throttle by hand.

One of the major costs for these type of systems are the charging costs. Four different options are identified by how these operations are performed. They are summarized below.

Option 1 In-house pick-up: Charging operations are performed by in-house employees. Starting from decentralized hubs across the city with an empty van, they perform tours to pick up e-scooters in need of charge. They return to the hub when maximum capacity is reached, where they unload the scooters to plug them in for charge. They perform as many tours as possible within their shift. In the next morning they are redistributed over the city in the same way.

Option 2 Gig workers: Gig workers stand in for charging the vehicles. These could be freelance workers or users of the system. They collect the vehicles at night and redeploy them in the city the next morning in change for a fixed fee.

Option 3 Combo: This option is a combination of option 1 and 2. A percentage should be set on the proportion performed by in-house employees. The remainder of the work is performed by gig workers.

Option 4 In-house swap: Charging operations are performed by in-house employees. Swapping batteries happens in the same fashion as in option 1. A van loaded with full batteries leaves the hub for a milk run on which empty batteries are swapped. If needed, damaged or bad-positioned vehicles can be picked up. A second shift in the morning is not needed by this model.

III. Methodology for Assessing Micro-Mobility Providers

The objective of this paper is to derive financial viability conditions for the bike sharing and e-scooter providers. This will be done primarily based on their cost structures. Figure 3 shows the generic work flow, starting with the construction of a cost model from which the Net Present Value (NPV) and Annual Worth (AW) of the total cost can be calculated. A standard sensitivity analysis by varying the figures of different cost categories will permit to discover the most important levers or cost drivers of the considered system. Based on this knowledge, targeted and well-chosen scenarios can further be analysed. By coupling an average demand input to the obtained AW of the costs, it is possible to calculate the break-even pricing. The minimum viability conditions will be in the form of minimum demand needed and or improvements in other aspects such as life expectancy or production cost of the vehicles.

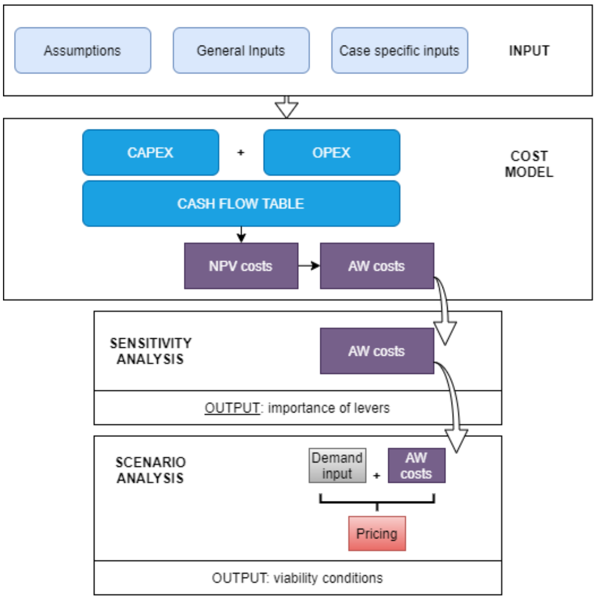


Figure 2: Generic flow of the analysis

A. Cost modelling approach

Cost modelling was done using a work breakdown structure (WBS) as framework. On level zero, there is the considered system from which the total discounted cost needs to be estimated. The different costs are categorized in one of the level one categories being: platform, assets, operations, IT & marketing, administration or management and overhead costs. The total discounted cost of the system is obtained by estimating all cost drivers in this WBS, see Figure 4, in a bottom-up way.

These costs are further categorized as being CapEx or OpEx or equivalently one-off or recurring. This identification is done to construct a monthly cash flow table from which the Net Present Value (NPV) or total discounted cost (TDC) is calculated.

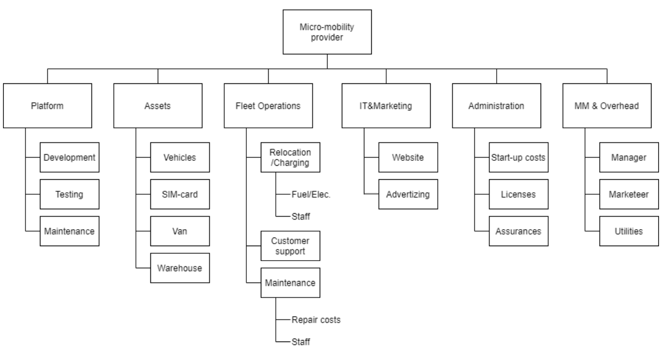


Figure 3: General WBS for micro-mobility providers

B. Data input

The input data is divided into three categories for clarification. The first category are the general modelling assumptions that are used for all cases. Secondly, there are generic inputs for both cases. These are for example cost estimations that are the same for both cases, such as utilities costs. Thirdly there are case specific inputs, such as the purchase prices of the different vehicles.

The general assumptions are needed to make the cash flow tables. A time horizon of 5 years is chosen. This is similar to the bike sharing studies discussed in the literature review. Price increase over the years is reflected in the cash flow table by applying an inflation factor of 2%. This is the targeted inflation and Belgian average. Costs (and revenues) that occur in the future are discounted with a discount rate of 15%. The net present value (NPV) can be calculated with the discounted costs.

C. Relocation cost modelling

As explained, the implemented relocation strategy is a static and operator-based relocation. The problem can be interpreted as a variation on the classical vehicle routing problem (VRP), namely the pick-up and delivery problem (PDP). Applied to the relocation of the bikes, a van starts at a central warehouse and arrives at the first pick-up station, where it picks up the load (amount of bikes that need to be relocated) and transports them to their destination (station with low bike density). Considering the amount of work and time this takes, one van or employee can perform multiple rebalancing operations within the time slot of the shift.

The costs that are considered in the calculation of the relocation cost are fuel costs and wage costs. In order to calculate them, an estimation of the above-mentioned PDP tours needs to be made. The length of the tours allow to calculate the duration of relocation operations and subsequently to derive the minimum amount of full-time employees needed to perform the relocation within the given time slots.

In this model, the amount of relocation to be performed is linearly dependent on the operational area size. Larger cities require more relocation operations. Validation of this model indicates that the majority of the relocation cost is incurred by wage cost for staffing. A good estimation of this cost thus comes down to selecting the right amount of FTEs and days to perform relocation activities.

D. Charging cost modelling

The need for charging the e-scooters is incurred by the battery consumption due to usage. By considering the battery capacity and average daily consumption, it is calculated how frequently the e-scooters need to be charged. Depending on the charging option considered, scooters in need of charge are collected in a specific way. As in the relocation modelling, the duration to perform these activities is calculated and translated to the amount of FTEs needed. The charging cost is then implemented as the sum of electricity cost, wage cost and fuel cost. Validation and decomposition of the total charging cost showed again that it is almost entirely incurred by wage costs.

IV. Results Case 1: Hub-centric bike sharing provider

This section will go into depth on the results of the cost model for hub-centric bike sharing providers. By performing sensitivity analysis on the different cost categories, the most important levers in the system are discovered. Targeted scenario analysis evaluates the impact of varying certain parameters more detailed to derive the minimum viability conditions.

A. *Cost analysis*

The total discounted cost of this system is estimated at €2,7 million or an annual worth of around €800.000. It is clear that the operational costs are the most significant with an overall percentage of 38% of the total cost of the system (Figure 4). This was expected due to the labour intensive operations such as relocation and bike repair. The second largest category with 29% is management and overhead costs, however these costs cannot be reduced, since they are largely induced by staffing costs. On the third and fourth place, a significant amount of cash is spent to platform maintenance and initial investment (15% and 9%). In this base case, the development and maintenance of the platform are done in-house.

Sensitivity analysis on the detailed cost groups helped to discover the major levers in the system. Hardware costs can be considered as less important. Most contributing cost categories are related to wage costs for different type of employees. Depending on the fleet size considered, maintenance workers become the most contributing wage cost, followed by operating staff for relocation. The relocation efforts are set at a minimum effort of 3 days performed per week for being able to derive minimum conditions. A last significant contributing factor in the system is the platform cost.

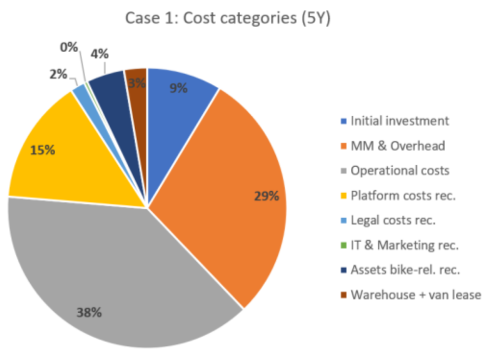


Figure 4: Case 1 cost categories based on NPV

B. *Scenario analysis*

The analysis was made between in-house software development and maintenance on the one hand side and outsourcing software costs to a third party on the other. Over a time horizon of five years, there is little difference between both options. However, outsourcing gives a significant buffer in cash savings against less revenue expected in the first phase of operations. It was demonstrated that a cost of up to 20% of the revenue generated for outsourcing software, would permit operators to financially opt for outsourcing.

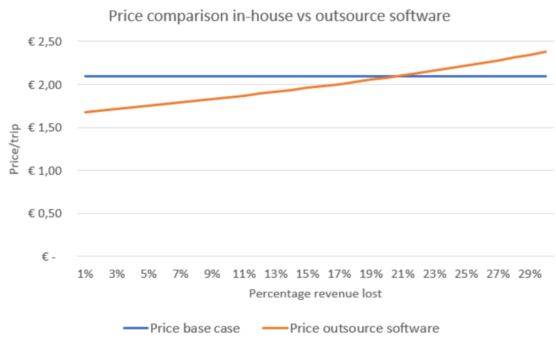


Figure 5: Pricing for in-house vs outsourcing software

The scale effect of increasing the fleet size within one city on the costs is observed to be clearly positive. The costs per bike decrease significantly up to and even beyond 1.000 bikes. The impact of optimizing the fleet size around an optimum for a fixed market size was found to be negligible. The additional cost of deploying one extra bike, assuming no extra employees should be hired, is only € 0,69 per day. This is equivalent to a price increase of only 1 cent per 20 extra bikes in the system. This relatively low compared to current pricing schemes of € 1,7-2,2.

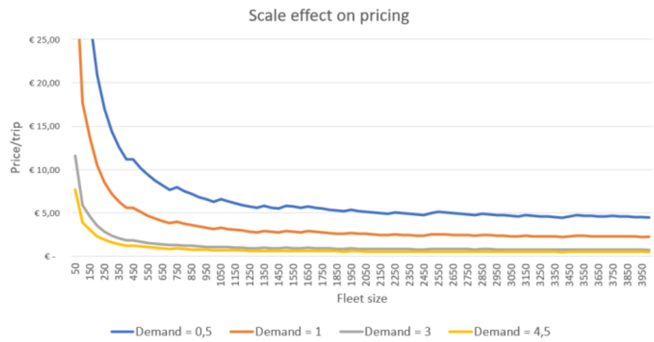


Figure 6: Case 1 scale effect on break-even pricing for different demand inputs

Increasing the fleet size too far to reduce the cost per bike, makes no sense without considering the demand each bike can generate. Real-life scenarios are created with a limited fleet size and low average demand of 0,5 rides per bike per day. It can be concluded that current providers are not viable at all with current pricing schemes as seen in Figure 6. Depending on the considered fleet size deployed, an average between 1,2 and 2,6 rides/bike/day make the system viable. The target of 3 rides/bike/day can make small systems of 350 bikes already viable.

Finally a best case scaling up scenario was considered for a typical Belgian city. The existence of current station-based large scale bike-sharing systems in cities like Brussels or Antwerp, could be the limiting factor in market size. If FF bike sharing market size could replace the existing SB systems with the same market, cities like Antwerp could permit up to 10 players to deploy up to 500 bikes while all being viable with the current pricing schemes of around €2 per ride. In such markets, large operators can have a significant advantage in competition with small operators. Depending on the difference in fleet sizes, large operators can permit themselves to offer significant lower prices which gives them the competitive advantage.

V. Results Case 2: Free-floating e-scooter providers

The same analysis was performed for the case of free-floating e-scooter providers. There are actually three different operational models, based on the charging strategy, analysed simultaneously. Option 3 describing the combination of charging by in-house employees and by gig workers is omitted. This is because it is hard to estimate the proportion of each option by which charging is performed. Depending on this parameter, different outcomes would be obtained and no unambiguous conclusions could be drawn.

A. Cost analysis

For option 1 with in-house employees performing charging operations by picking up scooters, the total discounted cost is estimated at €8,4 million or an annual worth of around €2 million. Almost half of the TDC is incurred by scooter-related recurring costs with 49% as seen in Figure 7. This is expected due to the high production cost and very limited life expectancy. Operations are again the second largest cost driver with 27%.

Sensitivity analysis indicates scooter recurring assets costs as most important driver as well. Improvements on hardware such as increased life expectancy and reduced production cost by mass production are expected and will be evaluated. Besides the hardware costs, charging operations come out as second most important cost in the spider plot. This operation is highly labour-intensive and a result of important operational choices. As mentioned earlier, charging operations can be done in-house or outsourced to gig workers. Lastly, the introduction of swappable batteries is mentioned as one of the key drivers to reduce the charging cost. All options will be further evaluated in the scenario analysis. As for the bike sharing system, platform development and maintenance costs are significant and outsourcing these costs are a possibility as well, but the analysis will not be repeated here.

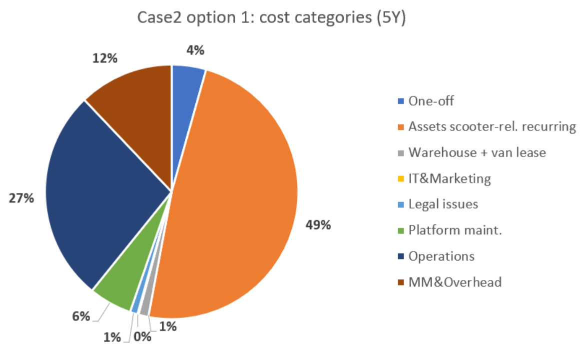


Figure 7: Case 2 cost categories based on NPV

B. Scenario analysis

A first scenario was created to consider the improvements in hardware costs. An increase in life expectancy of the scooters from 2 to 6 months results in a cost decrease of around 30%. Prolonging this further to the desired 12 months results in a decrease up to 40%. Life expectancy will thus be a key driver for viability for this type of provider. In the base case, production costs are estimated at €500 and it is evaluated that a 10% cost reduction is possible for every €100 production cost decrease. In the best case scenario a cost of €300 is targeted. A current, average and best case scenario was constructed by varying these two factors respectively from 2 to 6 and 12 months, and from €500 to €400 and €300.

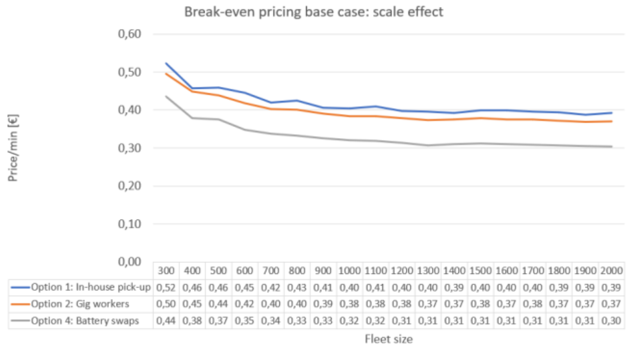


Figure 8: Case 2 break-even pricing for varying fleet sizes

In the base case scenario, an average demand of 3 rides per scooter per day is assumed. The scale effect on pricing with this demand is shown in Figure 8 and a stagnation can be seen around 1.000 scooters. The importance of optimizing the fleet size is again evaluated by calculating the marginal cost, which is estimated at €10,6 per day per additional scooter or equivalently a 5 cent price increase per 65 scooters. This is a significant increase of 20% when considering current pricing schemes of 25 cents/minute.

At this demand level, it can be seen from Figure 9 that neither small nor large operators are viable with current pricing schemes of €0,2-0,3/min. Moving to the average case already makes the small scale operator with 300 bikes viable. When only considering the improvement in life expectancy, operators can become viable at small scale for increased life span of 8 months, while at larger scale of 1.500 one gets in the mentioned pricing scheme already from 3 to 6 months. If a fixed market for a city like Brussels is considered with a demand of 15.000 rides a day, only two players with a size of 1.500 scooters can be viable. These large players have again the advantage in competition with smaller players by having the opportunity to give lower prices. However, if current pricing schemes are adopted, operators at a scale of 300 scooters can survive in the presence of larger ones if they move to the average scenario with the reduced purchase price and increased life expectancy.

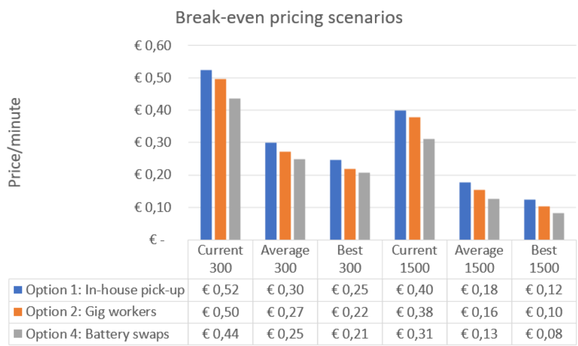


Figure 9: Case 2 break-even pricing scenarios

Finally, the charging costs are evaluated by looking at the outcome of all scenarios. The options that are currently applied in existing firms are charging by in-house employees by picking up scooters from the streets and charging them overnight at the warehouse or charging by paying gig workers a fixed fee for charging the scooters at home. The comparison between these two options showed that paying gig workers will always be slightly less expensive. However, the difference in pricing is negligible in most cases. Hiring in-house employees to perform charging is therefore advised, because there is more control over the operations.

Currently, some operators are converting their fleets to scooters having swappable batteries. The operations to perform charging are more efficient, because no extra shift is needed in the morning to redistribute the charged vehicles in the city. Looking at the AW of the costs that are translated to break-even pricing, a price reduction of up to and beyond 20% is possible depending on the considered scenario. These more efficient operations can thus be concluded to be a potential additional driver towards viability.

VI. CONCLUSIONS

A techno-economic analysis to derive minimum financial viability conditions for micro-mobility providers was performed in this work. Out of a set of possible providers, hub-centric bike sharing and free-floating e-scooter providers were selected to serve as use case. The aim was to make a decent financial assessment of operationally active systems, where the focus of current literature on this topic is more on planning and design of different aspects.

By constructing a dynamic cost model, the total discounted cost could be calculated for different scenarios. Starting from this cost model, different analysis are performed. The most important drivers of the system are discovered and scenario analysis permitted to derive tangible conditions. By coupling an average demand input to the cost model, current pricing schemes could be benchmarked.

Current hub-centric bike sharing providers were not found to be viable at a demand of 0,5 rides/bike/day with a price of €1,7-2,2. Increasing this demand level is the most important driver towards viability. Depending on the considered fleet size, an average demand between 1,2 and 2,6 rides/bike/day should be targeted. An important note should be made that these results are under the assumption of the considered relocation model, which was found to be an important cost driver. In real life, the optimal level of relocation should be made in combination with the effect on the targeted demand.

In line with studies on unit economics of free-floating e-scooter providers, it is observed in the analysis that costs are higher than revenue generated per ride. However, the gap towards viability can be overcome by increasing the life expectancy of the scooters. At a scale of 1.500 scooters, an increased life span to 4 months would already make it viable. Finally, charging operations for a fleet with swappable batteries was found to decrease costs significantly as well.

Future work on this topic could broaden the scope from the studied use cases to others, such as e-bikes, mopeds, etc. The combination of services through one single platform could be studied as well. The integration of services by a MaaS provider could have an impact on the demand. If this effect can be estimated, a new business case can be constructed. Lastly, this work was limited with amount of available data. Collaboration with existing companies or use of public data would permit to construct a statistical cost model based on real operational data to finetune and optimize cost estimations.

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REFERENCES

[1] D. Holland-Letz, M. Kässer, B. Kloss, and T. Müller, 'Mobility startup and investment trends 2019', *Mckinsey*, 2019. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/start-me-up-where-mobility-investments-are-going. [Accessed: 12-Apr-2020].

[2] T. Möller, A. Padhi, D. Pinner, and A. Tschiesner, 'The future of mobility 2020', *Mckinsey*, 2019. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-mobility-is-at-our-doorstep. [Accessed: 12-Apr-2020].

[3] Y. Wang, 'How China's Bike-Sharing Startup Ofo Went From Tech Darling To Near Bankruptcy', *Forbes*, 2018. [Online]. Available: https://www.forbes.com/sites/ywang/2018/12/20/how-chinas-bike-sharing-startup-ofo-went-from-tech-darling-to-near-bankruptcy/#3e4fd65466e6. [Accessed: 12-Apr-2020].

[4] K. Kokalitcheva, 'E-scooter startup Lime shuts in 12 markets, lays off around 100', *Axios*, 2020. [Online]. Available: https://www.axios.com/e-scooter-startup-lime-shuts-in-12-markets-lays-off-around-100-d25d44e4-c0f1-4713-9a89-868f4da40e03.html. [Accessed: 12-Apr-2020].

[5] 'The hub-centric model - Donkey Republic bike-share for cities', *DonkeyRepublic*. [Online]. Available: https://cities.donkey.bike/bike_share_hub-centric-model/. [Accessed: 14-Mar-2020].

[6] L. Caggiani and M. Ottomanelli, 'A Dynamic Simulation based Model for Optimal Fleet Repositioning in Bike-sharing Systems', *Procedia - Soc. Behav. Sci.*, vol. 87, pp. 203–210, 2013.

[7] T. Bulhões, A. Subramanian, G. Erdoğan, and G. Laporte, 'The static bike relocation problem with multiple vehicles and visits', *Eur. J. Oper. Res.*, vol. 264, no. 2, pp. 508–523, 2018.

[8] P. Leclaire and F. Couffin, 'Method for Static Rebalancing of a Bike Sharing System', *IFAC-PapersOnLine*, vol. 51, no. 11, pp. 1561–1566, 2018.

[9] L. Caggiani, R. Camporeale, M. Ottomanelli, and W. Y. Szeto, 'A modeling framework for the dynamic management of free-floating bike-sharing systems', *Transp. Res. Part C Emerg. Technol.*, vol. 87, no. April 2017, pp. 159–182, 2018.

[10] S. Reiss and K. Bogenberger, 'GPS-Data Analysis of Munich's Free-Floating Bike Sharing System and Application of an Operator-based Relocation Strategy', *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2015-Octob, no. 4, pp. 584–589, 2015.

[11] B. Legros, 'Dynamic repositioning strategy in a bike-sharing system; how to prioritize and how to rebalance a bike station', *Eur. J. Oper. Res.*, vol. 272, no. 2, pp. 740–753, 2019.

[12] A. Ajao, 'Electric Scooters And Micro-Mobility: Here's Everything You Need To Know', *Forbes*, 2019. [Online]. Available: https://www.forbes.com/sites/adeyemiajao/2019/02/01/everything-you-want-to-know-about-scooters-and-micro-mobility/. [Accessed: 14-Mar-2020].

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Abbreviations

AW	Annual Worth
BA	Business Architecture
B2B	Business to Business
B2C	Business to Customer
D&M	Distribution and Marketing
FF	Free Floating
FTE	Full-time Employee
GPS	Global Positioning System
HC	Hub Centric
IoT	Internet of Things
MaaS	Mobility as a Service
MSP	Mobility Service Provider
NPV	Net Present Value
PDP	Pick-up and Delivery Problem
PPP	Public Private Partnership
PT	Public Transport
PV	Present Value
SB	Station Based
SMP	Shared Mobility Provider
TDC	Total Discounted Cost
TNC	Transportation Network Companies

VRP	Vehicle Routing Problem
WBS	Work Breakdown Structure

Chapter 1

Introduction & Motivation

The mobility landscape is in a disruptive mood. Only a minority of industry players does not agree that impactful changes are going through the industry, and that the mobility ecosystem will look very different a couple of decades from now. Telecommunication technology has enabled the rise of new models for ad-hoc mobility and payment. Investments in new mobility start-ups have increased significantly. Since 2010, investors have poured $220 billion into more than 1.100 companies across ten technology clusters, among them battery improvement, e-hailing, charging, AV software and connectivity [7].

A popular and rather new concept in the sector is Mobility-as-a-Service (MaaS). In this concept, transportation services are offered to customers for shared use, compared to the traditional view of needing to have ownership of several transportation means. On one side of the value network, mobility providers, such as shared bicycle operators, shared car operators, public transport providers, and others are expanding their offers, while on the other, MaaS providers are integrating different modes of transport and offering seamless mobility to end-customers.

Due to the introduction of MaaS in recent years, the mobility landscape looks very disaggregated. Besides the more traditional mobility options such as public transport (PT), taxi-like services and other, there is the rise of new Mobility Service Providers (MSPs), such as bike sharing, moped sharing or e-scooter providers that keep innovating their fleets under the concept of MaaS. McKinsey [8] reported in December 2019 that the market potential across China, United States and China could reach $ 300 to $ 500 billion by 2030. Micro-mobility companies increased their investments by a factor of more than five from 2014 to 2018. Total investments now significantly exceed $1 billion already, with an average investment of about $100 million per transaction in 2018 [7].

However, currently it is far from sure whether these new MSPs add significant value to the mobility ecosystem and if they are or could ever be profitable. It seems that lots of small and larger initiatives are driven by a first-mover advantage, while probably being loss-making. In 2018 one of China's largest bike sharing start-ups *Ofo* went from raising more than 1 billion dollars to being on the verge of bankruptcy in only four years [9]. The reason that is given is the immense cash flow pressure driven largely by great competition in a market that still has to be proven to be commercially viable, analysts say. Attempts to become profitable have been done by trying to cut down operational costs drastically. To give another example, the reputable *Mckinsey* consultancy company reported about the favourable unit economics and lower break-even points of shared e-scooters [10]. Despite these perspectives, large players like *Uber*, *Lime* or *Bird* are not able to present profit numbers to its investors. Scooter company Lime is laying off about 14% of its workforce (roughly 100 employees) and shuttering operations in 12 markets as it seeks to become profitable. After two years of explosive growth, scooter companies have entered a new phase, namely survival of the fittest in a capital-intensive, money-losing industry [11].

This research project is initiated with this background. It is the aim of the research to investigate operational business models of mobility providers and derive minimum financial viability conditions. One of the first questions that will be answered is which levers or parameters really drive the value or costs of mobility providers. Based on this knowledge, it will be possible to discover and derive the conditions under which providers could be viable in specific scenarios. Viability conditions will be in the form of average demand needed, competitive price setting or minimum scale to operate at. On the industry level, important questions are whether specific systems have sufficient economies of scale or if multiple competitors can coexist within the same micro-market. Those are the questions that will be answered by this project.

Chapter 2 summarizes the literature study. The first part deals with the complete MaaS ecosystem which needs to be understood. The relationship between different stakeholders and the position of mobility providers within the system need to be known in order to fully grasp the impact on the cost structures. In a second part, previous cost modelling works will be discussed. Important operational aspects such as relocation and charging are explained in greater detail as well.

The methodology applied in this work is given in Chapter 3. An overview and classification of all mobility providers is made first. Only a subset of these providers is chosen to investigate. It is opted to do this research on several micro-mobility providers, because of the more recent development and rise in combination with the innovative technologies. From a techno-economic perspective, all building blocks to make a dynamic cost model are explained, to end up deriving the viability conditions.

Finally, Chapters 4 and 5 discuss the results obtained from and the analysis on the cost models for two types of providers. These are bike sharing and e-scooter providers. The analysis consists of a standard sensitivity analysis followed by specific scenario analysis. This will become more clear when going through these chapters. For both types of providers, existing use cases are studied as well to benchmark their current viability based on the conditions discussed above.

Chapter 6 summarizes all findings and lists all recommendations for the most important scenarios. An overall conclusion on the research project is given together with possible future improvements or further investigations.

Chapter 2

Literature study

In this chapter, all relevant and necessary background literature and information to perform this project is explained. It starts with elucidating the concept of MaaS under which mobility service providers could operate. Mobility-as-a-Service is often referred to strictly as the link in the ecosystem that bundles multiple modes of transport and offers them as a package. However, mobility service providers, which are one of the stakeholders in the network, can operate using their own service platform as well and thus also offer mobility as a service. In this thesis, the broader vision of MaaS, being any company that offers mobility solutions as a service, such as bike or e-scooter sharing companies, is taken. However, parallels can be drawn between the two visions on the business model in the sense that both have a similar value network and interactions with other stakeholders.

In a second part of this chapter, one type of mobility service providers is described on greater detail, namely the shared mobility providers (SMPs). Shared mobility is explained as a phenomena in the rising use of shared economy and some implications are briefly discussed. The reason for highlighting this group is because through the process of this work, it was opted to use two innovative and upcoming shared mobility options as use cases. These are shared bicycle and free-floating e-scooter providers. In the final part of this chapter, an overview is given of previous case studies on the economical and operational performance of these systems. The elaboration of the cost structures in this project will be partly based on the knowledge gathered from these case studies. One of the most important operational aspects for these systems are relocation and charging strategies. A prior literature study on both strategies was necessary to understand the impact on the performance and to model them as a cost, which will be explained in a later chapter.

2.1 Mobility-as-a-Service

Mobility-as-a-Service (MaaS) is a rather new and upcoming concept or path taken in the mobility sector. As stated in the introduction, it tries to offer a multi-modal mobility package as a shift away from individual ownership of transportation means. In this system it is convenient to switch between different modes of transport, such as train, metro, bike, taxis, busses or by foot and this all according to the use pattern of the end user. The emphasis is on offering mobility as a service as needed by the user instead of being in the possession of some modes at all times. It is in this context that lots of new mobility service providers (MSP) have emerged. There are several possibilities by which these MSPs could or could not be integrated in the MaaS ecosystem. These different options and aspects will have a noticeable impact on the cost structures of these providers. Therefore, it is important to know how all stakeholders interact with each other within this ecosystem.

2.1.1 What is Mobility as a Service?

In recent years, the amount of literature on this topic has increased from almost non-existent to a broader range of relevant papers. Earliest papers in the existing literature have a large focus on the concept and the definitions of MaaS. Kamargianni & Matyas define MaaS as a user-centric, intelligent mobility distribution model in which all mobility service providers' offers are bundled by a single provider, the MaaS provider, and offered to the end users by a single digital platform [1]. MaaS is explained as a technology-enabled mobility management service where the customer interface and business back-office are integrated [12]. Many other definitions and papers can be found that focus on the concept of MaaS as being a user-centric model. The current situation and the MaaS model from the user's perspective is displayed in Figure 2.1. On the right hand side it can be seen that a user interacts with a MaaS provider to buy a tailored mobility package including multiple modes of transport, while on the left the user needs to buy all options separately.

From a public point of view, EMTA [2] describes MaaS as a mean for integrating all existing and new, public or commercial transport modes and it does not generate transport capacity itself. It is a solution for potential customers to manage their travel needs through one unified service. This definition coincides with the one displayed in Figure 2.1. Besides that, it also generates insights into travel behaviour and needs for cities or governing bodies, allowing to make more targeted or efficient changes in infrastructure or policy making.

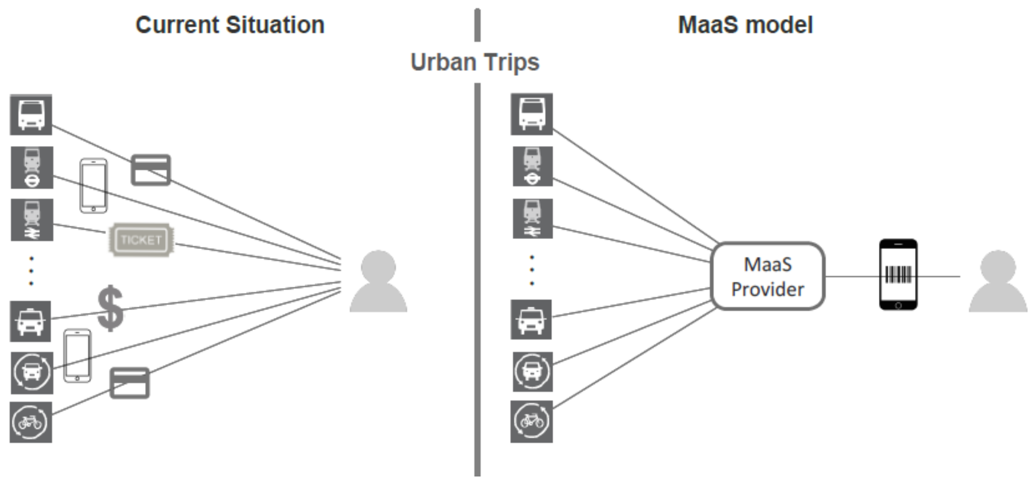


Figure 2.1: With and without MaaS from user's perspective [1]

2.1.1.1 Benefits of MaaS

MaaS has great potential to offer a comfortable and efficient alternative to using and owning a car in city centers. Therefore, a shift towards a more sustainable urban mobility is possible [13]. Maas could have the potential to generate sustainable value for the society as a whole instead of only for individuals [14]. This value can be in the form of reduced road congestion. Switching to a shared economy with smart mobility, which MaaS is, might be a crucial element in tackling road congestion [15], by decreasing the amount of vehicles on the road.

From the user's perspective, it can help to plan trips with the transportation mean that they need at the moment. This way, individuals may save time and money and be more flexible. Being less dependent on ownership will permit a larger group of people to participate in social activities, reduce isolation, and increase accessibility to education, health care and other services [2].

The information collected from all users can be used to enhance infrastructure or public transport policies. Dynamic pricing could be a way of using this data to tackle congestion on peak hours and reduces the need of infrastructure [2]. This in turn can again be profitable for the transport experience of the individual.

2.1.1.2 Implications and obstacles of MaaS

Karlsson, Sochor, & Strömberg [16] focus on developing the service in MaaS for the *UbiGo* project in Gothenburg. Although the overall results indicated a positive attitude towards the concept, there were some implications made clear. The first one is the much-needed financial support to develop a fully operational service with well-functioning back-end support. This is often a problem for many start-ups facing the problem to raise enough money. The second factor is related to regulatory issues connected with offering the government supported public transport services in to a commercial concept. Conflicts can occur due to unfair competition. Lastly, becoming a MSP to the MaaS provider involves relatively new partnerships between them. Becoming a service provider to a MaaS could involve modifications to the existing business model including pricing etc. By integrating in such platform, these providers will need to negotiate on profit-sharing which can be a deterring factor. These concerns are all related to the business model.

From the user perspective, there could be the implication to shift from using well-known, already existing routing planners from individual companies towards using a single MaaS application [13]. Examples of existing apps are those of car-sharing, bike-sharing or other companies. These MSPs nowadays have the option to offer their services through their own platform or by integration in a wider MaaS app. Both scenarios will be investigated in a later chapter. The biggest challenge however, could be to change the mindset of the people towards car ownership [12]. A shift to a more and more sustainable attitude of the millennial generation, could be an important factor in order for MaaS to succeed.

A last implication connected to deploying MaaS is concerned with the policy framework for implementation that is required. When trying to make MaaS operational on a global scale, there are concerns about competitiveness. The MaaS market could be dominated by few large players [13]. This can result in a monopolistic behaviour of the market with higher prices and less quality by lack of competition. Another obstacle in the concept is the use of open data and ICT. Cooperation between different cities belonging to different authorities may be an issue. A strong policy framework is thus required before the implementation of MaaS is possible.

2.1.2 MaaS ecosystem

A business ecosystem is a wider network of stakeholders or firms that have an influence on how a central firm creates and captures value [17]. From the perspective of the MaaS provider as the central firm, it interacts with many other players from which the function within the system should be identified. An elaborate representation of this ecosystem is depicted in Figure 2.2, which consists of multiple layers [1].

In the core business, the MaaS provider interacts primarily with data providers, transport operators (MSPs) and the end users or customers. In the extended enterprise layer, all components are integrated that are necessary to create the value and can be seen as complementors or second-layer suppliers. These are for example the technical back-end providers, payment solutions, ticketing firms or insurance companies. The most important stakeholders, from the point of view of the MaaS provider, are further discussed in the next section.

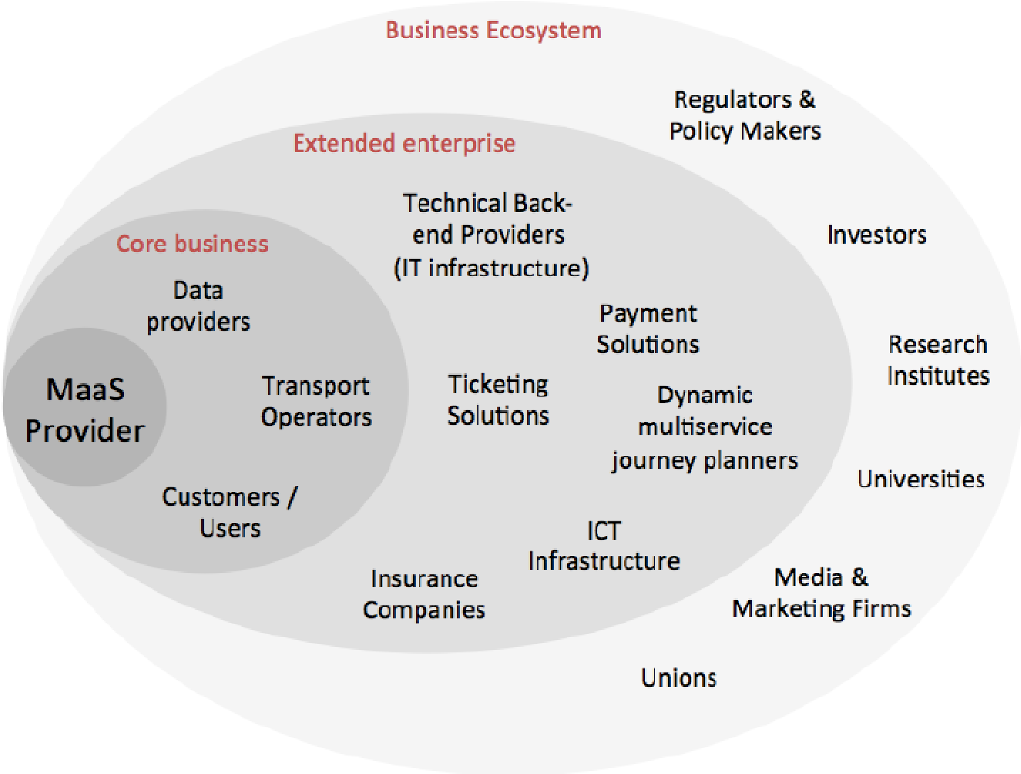


Figure 2.2: The Mobility-as-a-Service Ecosystem [1]

From a public perspective, another aspect in the ecosystem that is not yet incorporated in Figure 2.2 is infrastructure, such as stations, public space, roads and parking [2]. Both the current mobility market and the MaaS mobility ecosystem as seen by EMTA is shown in Figure 2.3. They emphasise that there are two additional elements in the system, being the *Service Provision* and *Data and System Integration* layer. The former coincides with the role of the MaaS provider combining all modes of transport to provide the customers with multimodal services. To do so, the service provider needs all relevant data such as availability of vehicles, free parking space or routing and pricing information. The

Data and Systems Integration layer has the role to integrate all relevant data from these different players in the ecosystem. These two additional elements are seen as key elements for regulation and implementation of a well-functioning MaaS business model.

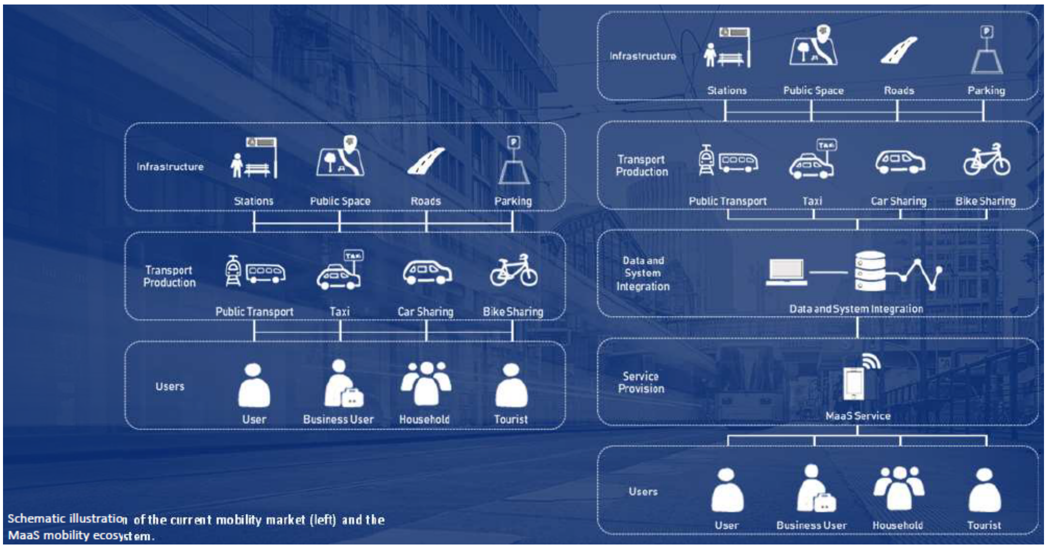


Figure 2.3: Current mobility market (left), MaaS ecosystem (right) [2]

2.1.2.1 Stakeholders

As stated above, the core business of the MaaS ecosystem consists of the MaaS provider, the customers/users, the mobility service providers and data-interested institutions. The latter stakeholder is incorporated in the system, because aggregated data from traveling patterns or usage rates can be sold by the MaaS provider as a value adding service to interested institutions. The relationship between the stakeholders can be vizualized best in a value network as shown in Figure 2.4. Value network analysis offers a tool to model, analyse, evaluate and improve the capability of a business to convert both tangible and intangible assets into other forms of negotiable value [18]. Intangible assets could be the information or knowledge about transportation assets by the the MaaS provider and are illustrated by the dashed line in Figure 2.4. Tangible assets can be physical or just have a financial value such as money and is displayed with the solid lines.

MaaS provider

In the strict definition as given in the first section of this chapter, the MaaS provider is responsible for aggregating multiple modes of transport into a single mobility offer. The legal body that could stand in as MaaS provider has two options [1]. It could be regulated

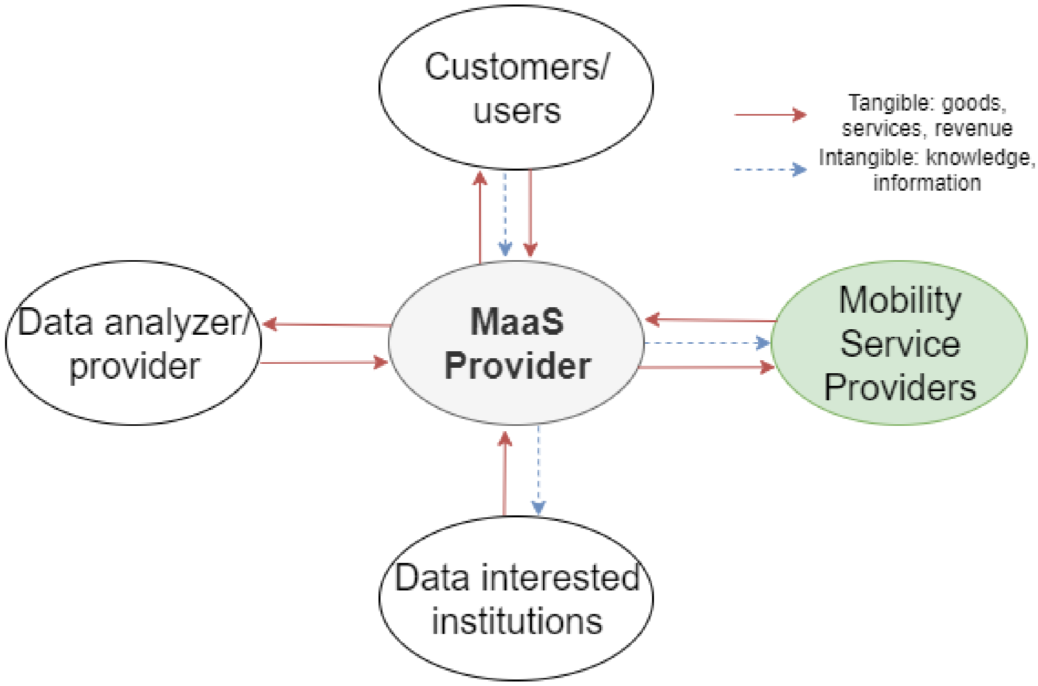


Figure 2.4: Value network for a MaaS provider

and organized by a public transport authority (and equivalently the government) or a private firm could be the operator. Benefits of a public authority as an operator lies within the ease of integration of public transportation means into the service package. Another benefit is that these public authorities are often the transport regulators as well, so that regulation of the concept may take less time. Disbenefits could be to integrate the profit-making service providers with the not-for-profit public transport providers resulting in unfair competition. Innovation could also be slowed down by the not-for-profit character of this authority. A private firm operating as MaaS provider has the advantage of being driven by profit maximization and would lead to a faster development of the market. From the MSP point of view, this type of model is preferred as well, because they believe that there would be more incentives to promote their services.

To be able to offer the package, there should be contracts with mobility service providers. These are car-sharing providers, public transport, taxi's etc. Payment for these services can be per vehicle or per usage in normal circumstances. Through this mechanism, the MaaS provider is the link between the end customer and the mobility service provider. However, this is not the only link between the MaaS provider and the end users. Through their payments and usage patterns, lots of data are collected and sent to the MaaS provider.

Mobility service providers

Mobility service providers are the links that have the role to supply the MaaS provider with transportation means. As mentioned before, these can be private firms, such as car-sharing or bike-sharing companies, or they can be public transport authorities. They can benefit from the broader network of possible customers and hence they can enlarge their own market segment. In this way, they have the opportunity to grow their revenues.

From the point of view of this research, it is important to note that the MSPs could act independently from whatever MaaS operator and offer their services using their own service platform. This is also the point of view that is taken in this thesis and that will serve as base scenario in the use cases. When doing this, the MSP replaces the role of the MaaS provider in the value network in Figure 2.4 and has the same relationships and exchanges with the other stakeholders as the MaaS provider would have.

Customers/users

MaaS is by definition a user-centric model [1]. The vision of the concept is to add value to the customers. These customers can be individuals, companies or other institutions depending on the business model (B2B, B2C or both). The value that they experience is in the opportunity to experience a customized mobility offer as they need it. Customers won't need to buy multiple single tickets from different providers and will thus save time as well. As mentioned earlier, the MaaS provider is able to collect data from the customers, which could in turn lead to added value for them.

Data analyzers/providers

Data from the customers are collected such as travel patterns, usage rates or mobility package composition through the ticketing system. Data analyzers or providers are necessary players in the value network. They offer capabilities to the MaaS provider to collect and analyze the data in an efficient way. This can help the MaaS provider to optimize its offerings and operational performance. Besides that, they can stand in for the storage of the enormous amount of data.

Data interested institutions

Besides the revenues generated through the mobility package service to customers, there is a potential second source of income for MaaS providers. They can exchange the collected data to data-interested institutions. An example of such an institution could be the Flemish government, wanting to know the current usage pattern in order to optimize the transport infrastructure to reduce congestion.

2.2 Shared mobility providers

Within the value network of the MaaS ecosystem, the mobility service providers are of interest in this research. MSPs are public transport, taxi services, car-, bike- and scooter-sharing companies and others. This group of companies stand in for the transport supply to the value network of MaaS. The sharing services mentioned here, can be classified as shared mobility providers (SMPs). These providers, compared to the traditional PT and taxi-like services, have an innovative and potentially disruptive character. It is for this reason, that these providers are under investigation in this research. The next sections dig deeper into the understanding of shared mobility.

2.2.1 What is shared mobility?

Shared mobility is a form of sharing economy in the business of mobility. It entails the sharing of an asset, in this case for example vehicles, that is not owned by users, but accessed as a service. The distribution and access is mostly enabled by means of a digital platform. Shared mobility assets can be bicycles, e-bikes, mopeds, steps, scooters, cars or vans. The classification of all relevant systems will be discussed in a next chapter as part of the methodology. There are many examples around the world of incumbents and emerging new systems. Typically, shared motorcycles, scooters, bicycles and e-bikes are owned and/or operated by either private or public enterprises [19]. Van -and car sharing companies are most often private enterprises or P2P businesses. However, these could also be implemented by local authorities or at least be under their regulation. If implementing shared mobility systems is done from the point of view of increasing sustainability or reducing congestion, the schemes may be operated by public authorities. There are many already existing bike-sharing schemes in field nowadays.

To summarize, the common feature to all modes described above is that vehicles are shared and that access and payment are enabled by a digital platform. It must be noted that of course, car-pooling, car rental or public transport already existed before the Internet age. However, the Internet has enabled smarter ways of organizing and offering mobility to the users. This results in a more practical, modern and faster way of implementing new ideas.

2.2.2 Implications of current practices

The newest mobility service providers nowadays are mainly generated in city centres or for short-distance trips [19]. They should serve as an alternative to classical private car usage. There are many players active and the number is still increasing. However, many of them are having difficulties in finding sustainable business models. Bike-sharing systems are going bankrupt and innovative MaaS initiatives such as *Moovit* or *Whim* find themselves in the need of public funding to survive. Large ride-hailing companies such as *Lyft* and *Uber* have gone public on stock exchange promoting themselves as the future of mobility. However, both companies are still having difficulties to break-even and are in the need of seeking public partnerships.

Private operators are thinking from their commercial point of view compared to what local authorities have in mind when thinking about MaaS. Commercial MSPs have the belief that they are needed to solve the mobility issues which public authorities can't address. Therefore, they want them to open data to private operators to organize a free and competitive market to be able to deliver a faster and cheaper service. However, a cooperation and complementarity between the services of commercial MSPs and traditional PT modes need to be sought. In a literature review on shared mobility it is mentioned as well that the introduction of these modes alone will not solve transportation problems in large cities. The implementation of shared mobility schemes thus provides the potential to improve efficiency, social equity, competitiveness and quality of life in cities [20].

2.3 Cost modelling in micro-mobility

The economics of new mobility service providers have not been the topic of many studies worldwide. A decent assessment of the financial structure and cost model is needed to derive the long-term viability conditions for these providers. Without knowing the financial viability of these systems, both private and governmental investors can't make well-supported decisions. By going through the available literature, some feasibility studies are found on existing North-American bike sharing systems. Best practices, implementation issues and propositions, operational aspects, demand patterns and financial cost drivers are things that are studied in these reports. They give a good look on what is needed in this research project. On the spectrum of available literature about cost modelling for e-scooter systems, only a handful of academic papers are devoted to the research of some operational aspects such as charging of the scooters, but never about cost modelling the entire operation of the system. On the other hand, many useful tech-blog and newspaper articles describing the different operational models and related costs are found. These are very useful to get a glimpse of how the cost modelling should be done and to obtain decent estimations of certain costs. However, the studies found, lack a lot of information and never consider all cost aspects which companies are faced with, such as marketing, customer support, warehouse rent etc.

2.3.1 Case studies on bike sharing

A first report from 2014 presents findings and recommendations regarding two bike sharing-related issues, namely potential economic impacts and the balancing problem [21]. They more particularly devoted a large part of their study to highlight common and noteworthy operations practices, which include rebalancing strategies and patterns for bike share employee practices, warehouse location and use, vehicle use, and technology for both public and private use. It must be noted that at the time of that study, there was no involvement of smart mobility, GPS-traceable vehicles or any other IoT application. One important aspect however that can be remembered from this study is the identification of four common methods for planning and coordinating rebalancing operations. These are (1) the use of a central dispatcher to direct rebalancing staff, (2) real-time communication between rebalancing staff to coordinate which stations to rebalance, (3) the option to work with predetermined fixed routes or (4) to divide the operational area in geographic zones for which different teams are responsible. Rebalancing is thus seen as a very important operation within bike sharing systems. For this reason, an extra section is devoted to different rebalancing strategies.

Two other and almost identical early studies perform a feasibility analysis for a bike share program in the region of St. Louis [22] and Redmond [23] (United States) and outline a business plan over five years for its creation. Useful information is given in the form of a business pro-forma together with a financial plan, identifying the costs and operational considerations for the program. Firstly, considering the business model, one of the key early decisions for a city or region exploring bike sharing is to determine a governance structure for the program – who will own the assets? Who will administer the program? Who will be responsible for day-to-day operations? It identifies four primary business models, being (1) publicly owned/privately operated, (2) non-profit owned and operated, (3) non-profit owned/privately operated and (4) for-profit owned and operated. These four options differ from each other by who is responsible for capital expenditure on the one hand-side, and who is responsible for the day-to-day operations on the other.

Both studies give a listing of all costs related to a bike sharing system. They divide the costs in four major groups, being launch and capital start-up costs, administration costs for the equipment owner and finally operating costs. A similar cost categorization was used in a bike share feasibility study in Truckee Meadows (US, 2017) [23]. They are listed below and will be used as well in the cost modelling of this project:

- **Launch costs**: This group includes hiring people, development of an IT structure and website, pre-launch marketing, station assembly and all other upfront costs that arise from setting up the program
- **Capital costs**: These costs are related to all material and equipment such as the bicycles itself, stations, GPS-trackers, gear and tools,... A note must be made that lots of these costs can vary depending on the desired level of quality and the selected operational model.
- **Administration costs**: Operating a bike share system requires capital and immediate administration costs to hire people and prepare roll-out of the system. In the long term, ongoing administration costs are those related to staffing, marketing and other general expenses.
- **Operating costs**: Operating costs include those required to operate and maintain the system. This includes staff and equipment related to:
  - **Station maintenance**: In case of a station-based system, the docking stations will need to be maintained regularly. This includes cleaning, repairing and solving technology-related issues.
  - **Bike maintenance**: This includes inspection and service of all bikes at certain times. It also includes all material inventory to perform the repairs.
  - **Customer service**: At least one person needs to be hired that stands in as first respondent for customer information and complaints.
  - **Direct expenses**: Deals with expenses that go to warehouse facilities, spare parts, insurances, IT maintenance and other recurring costs that are associated with keeping the program running.
  - **Rebalancing**: Finally, rebalancing operations will be needed to redistribute vehicles across the city to obtain a higher usage. These operations are caused by the imbalance of the system due to more and less popular destinations in a city.

2.3.2 Case studies on e-scooter sharing

In academic literature, no detailed financial studies can be found on shared e-scooter systems. Detailed case studies describing full cost modelling and cash flow analysis are non-existent as well at the time being. Most relevant information that can be found are tech-blog or newspaper articles discussing the evolution and critical parts of existing systems. These issues are mainly related to the high purchase/production price, very limited life expectancy, inefficiencies in operations and discussions on critical component design.

However, some instances have collected relevant cost estimations in order to calculate the unit economics of e-scooters. Unit economics are the direct expenses and revenues associated with a particular business model and is expressed on a per unit basis. Although it is not a full cost modelling approach, it allows potential investors or critics to get a quick idea of how scalable or profitable a business can be. It is important to be aware by evaluating these case studies that some major and relevant costs are being omitted in the calculation. For example, the renting of a warehouse is left out of consideration in most cases, while it is an indirect cost associated with operating the system. However, observing these case studies will provide a good basis for case-specific cost estimations that can be supplemented with the more generic costs.

A first simple unit economic discussion is found on the global business news website of *Quartz* [24]. Back in 2018, they stated that it is possible that e-scooter companies are attracting such tremendous sums of venture capital money, because the unit economics are actually good. Purchase prices are estimated between $300-$500, while charging is performed by gig workers at a fixed fee of $5 per charged scooter. However, other operational costs and parameters such as maintenance, rebalancing and the lifespan of the scooter are unknown. This first case study already gives some interesting cost categories, but is far from complete to perform a proper analysis on. Two similar back-of-the-envelope calculations add a cost estimation for the above-mentioned unfilled costs [25], [26]. Revenue is calculated with the same calculations. The cost estimations are explained below:

- A road-ready scooter comes at a cost of $400.
- A base case lifespan of 300 rides
- Charging costs of $5 per scooter by gig workers and $20 per scooter by own employees. Largest share of the latter cost is incurred by labour cost for picking up the scooter and return it. 50% is assumed for each type in the base case.
- Maintenance cost of $20 per scooter every 2 weeks.

Maintenance and charging costs for own employees are very rough estimates in this study. However, they permit to calculate the unit economics and gross margin for some simple scenarios. At this point, calculating gross profits and margins makes sense if the goal is to understand the scalability of the business.

When jumping one year later in time, the unit economics are still a worrying topic in tech-blogs and business newspapers. The biggest concern is the very low life expectancy of the scooters as reported in *Quartz* [27]. They state that a shared e-scooter in Louisville only lasted on average 28.8 days. Another source points out that there unit economics even indicate that the business is unprofitable at the time of writing (February 2019) due to the high costs per mile [28]. This study believes that there are lots of opportunities to cut down in costs such as the cost of the scooter hardware, the cost of charging/relocating them, maintenance costs, and credit card fees, as well as higher utilization rates and longer lifespans. The same suggestions for improvement are reported by the *Boston Consulting Group (BCG)*, that performed an analysis on the unit economics in 2019 as well [3]. By looking at the unit economics, they calculated a break-even point of 3.8 months while the average life expectancy in their study was only 3 months at that time. This is shown in Figure 2.5. In January 2020 they re-evaluated the business case of shared e-scooters and indicated that e-scooters' unit economics have improved significantly, and companies are innovating aggressively to overcome operational constraints [4]. Improved unit economics compared to 2018 are displayed in Figure 2.6. Main drivers are longer lasting batteries, higher prices and more durable and longer lasting scooters. However, besides hardware improvements, innovations in the operational aspects are a major contributor in the better unit economics. Getting rid of the excessive burden of charging operations are induced by introducing swappable batteries.

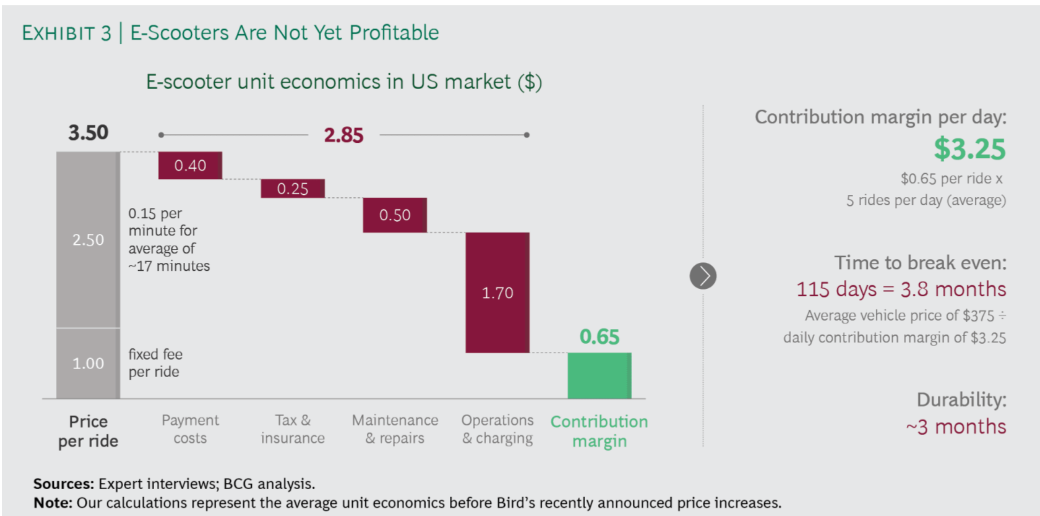


Figure 2.5: Unit economics of shared e-scooter [3]

How the Unit Economics Are Unfolding

THE EXPERIENCE OF A MAJOR PROVIDER

PER E-SCOOTER RIDE	2018	2019[1]	MAIN DRIVERS	OUTLOOK
Gross revenue	**$3.50**	**$4.27**	• General increases in per-minute price • Higher prices charged in high-adoption locations	≈
Discounts		$0.44	• Overall ~10% of gross revenue is expected	≈
Net revenue[2]		**$3.83**		
Charging[3]	$1.70	$1.04	• Larger, longer-lasting batteries mean less frequent charging • Gig workers are paid reduced fees for recharging	+
Repair	$0.50	$0.32	• Sturdier equipment means less frequent repairs • Large-scale operations cut cost per repair	+
Other variable costs[4]	$0.65	$0.25	• Primary driver is number of rides	≈
Variable margin	**$0.65**	**$2.22**	• Revenue per ride increases as operational costs decrease	+
Rides per day (full year, US)	5	2.3	• Average number per active e-scooter stays constant or increases slightly	≈
Expected vehicle lifespan (months)	~3	~15	• Equipment is designed for sharing, significantly increasing its half-life	+
Cost of e-scooter	$375	$630	• Co-development of sharing providers and Asian manufacturers limits cost increases	≈
Breakeven per e-scooter (months)	**3.8**	**4.0**	• Breakeven time remains stable, as a higher contribution per ride offsets fewer rides per day	≈

+ Improvement expected ≈ Neutral

Sources: Bird; BCG analysis.
[1]Four-week average (June 10–July 7, 2019) for Bird Zero and Bird One.
[2]Net of sales tax, credits, discounts, refunds, disputes, and failed payments.
[3]Includes operations and support costs (in-market labor, transport tasks, and other task payouts).
[4]Includes costs such as insurance, payments, mobile data, and cloud service hosting fees.

Figure 2.6: Improved unit economics of shared e-scooter [4]

2.3.3 Relocation strategies

One of the most important and complex operations that a mobility provider encounters, is the relocation of an unbalanced vehicle sharing system. These are incurred by one-way trips, originating from one station and ending the trip in another. For example, on a sunny day in a coastal city, in the progress of the day more and more trips will be taken to the beach, resulting in occupied stations at the beach and an under-capacity in the city centre. This will result in a lower usage rate in those places and less revenue. This problem is solved by actively rebalancing vehicles from one place to another.

Research performed on rebalancing operations for bike sharing systems deals with modelling the problem mathematically as an optimization problem. The most important and state-of-the-art studies have been analyzed in order to obtain insights in how the operations could be financially modelled in this research project. An overview of different possibilities, strategies and parameters to consider are given below.

Caggiani and Ottomanelli [29] mention that in current literature on bike sharing services relocation strategies, there are two types in general. These are the user-based and the operator-based relocation. The need for relocation is driven by the phenomena that bike sharing systems are often used for medium-long and one-way trips. The operator-based relocation problem is of interest in this study, because these costs need to be modelled. This problem is defined as the Pick-up and Delivery Problem (PDP). The rebalancing can be done during the night or on other fixed time slots (static repositioning) when demand is negligible or during the day when bike distribution across the city changes all the time (dynamic repositioning). The presented model is a dynamic decision support system that generates optimal repositioning flows, distribution patterns and time intervals between relocation operations.

Other mathematical studies on dynamic bike rebalancing all consider the stochastic demand patterns during the day [30, 31, 32]. Basically, the first step in solving the relocation policy problem, is the development of a demand model. This demand model forecasts the need of redistribution of the fleet based on historical data, properties of each day, temperature, season etc. An optimization algorithm then solves the redistribution problem to meet the desired demand level. In theory, this optimization problem can be solved as a vehicle routing problem (VRP). In the case of having only bicycles, this becomes more specifically a one-commodity traveling salesman problem.

On the static repositioning side of the literature, more recent studies are performed by Bulhoes [33] and Leclaire [34]. Important parameters on the applied strategies are found. These are for example the fact that static rebalancing can be done with multiple vehicles and multiple visits. It is often assumed that the relocation vehicles have the same capacity and can perform in any given service time limits. Often it is preferred to perform the operations during the night or in a maximum of two shifts a day.

No practical modelling information was found through the literature study. The most important take-away from this research is the existence of multiple strategies. First of all, there is the user-based or operator-based division. User-based relocation is done by giving incentives to users in the form of discounts to return the bicycle to a favourable position. Secondly, there is the difference between static or dynamic rebalancing. In both cases, relocation vehicles depart from warehouses and perform a pick-up and delivery tour to relocate the bicycles. In Chapter 3, it will be explained how the cost estimation of those tours is done by applying the general principles found in these studies.

2.3.4 Charging strategies

Some mobility service providers are deploying a fleet of electrically driven vehicles. One could think of e-bikes or more recently the e-scooters. It speaks for itself that there should be some way for recharging empty batteries in the vehicles. There are currently several strategies by which this is done. These are not found in academic literature, but in technology blogs and business newspapers. The different charging models are explained below.

A first model is discussed in many articles and unit cost calculations. Operators like *Bird* or *Lime* make use of so-called gig workers. These are users of the system or other people that take on the charging job in return for a fixed fee depending on the level of difficulty to find the scooter in need of charge. So every night people track e-scooters, collect them and take them home to charge, and redistribute them in favourable places the next morning. By working this way, electricity bills and costs for charging employees are replaced by a fixed cost per scooter.

A second option is to perform the charging operations with in-house employees [25, 26]. They estimate $20 per vehicle for charging a scooter by own employees. A majority of this figure is the cost incurred by the company to pick up each scooter from its current location, take it to the nearest charging point and to return it to an appropriate location once the charging is completed. The estimate of this cost seems unrealistically high and will be estimated in more detail in a later chapter. A third option is described as well as a combination of in-house employees performing the charging operations supplemented by a proportion done by gig workers.

Finally, a fourth option is considered in more recent analysis on e-scooter performance [4]. Introducing swappable batteries is predicted to be a major contributor into reducing operational costs and improving unit economics. Because they eliminate the need to retrieve, charge, and redeploy each scooter, swappable batteries reduce labor and logistics costs. *TIER Mobility* has recently been replacing its entire Paris fleet, as first e-scooter provider to do so, with vehicles having a swappable battery [35]. This new operational model will make the need to transport scooters to hubs for charging obsolete. A fleet of vans will enable local operations to quickly swap empty batteries and perform quick safety checks and relocation operations.

To summarize, there are four major charging models used by the operational active e-scooter providers. In the remainder of this project, they will consistently be referred to by their option number and descriptive name as shown below:

- **Option 1: In-house pick-up**: Charging operations are performed by in-house employees. Starting from decentralized hubs across the city with an empty van, they perform tours to pick up e-scooters in need of charge. They return to the hub when maximum capacity is reached, where they unload the scooters to plug them in for charge. They perform as many tours as possible within their shift. In the next morning they are redistributed over the city in the same way.
- **Option 2: Gig workers**: Gig workers stand in for charging the vehicles. These could be freelance workers or users of the system. They collect the vehicles at night and redeploy them in the city the next morning in change for a fixed fee.
- **Option 3: Combo**: This option is a combination of option 1 and 2. A percentage should be set on the proportion performed by in-house employees. The remainder of the work is performed by gig workers.
- **Option 4: In-house swap**: Charging operations are performed by in-house employees. Swapping batteries happens in the same fashion as in option 1. A van loaded with full batteries leaves the hub for a milk run on which empty batteries are swapped. If needed, damaged or bad-positioned vehicles can be picked up. A second shift in the morning is not needed by this model.

Chapter 3

Methodology for assessing Micro-Mobility providers

The objective of this project is to derive financial viability conditions for mobility service providers.This will be done for a subset of those providers based on a cost model. The first step in the methodology is to make a classification of all existing mobility services. This classification is done primarily based on vehicle type and secondly on service type. Operational or other aspects that have a possible major influence on the cost structure of the providers are used as a split criterion. After the classification is done, a subset of MSPs is selected to further investigate in this research project. The scope of the project will be limited to the subset of micro-mobility providers and more specifically bike sharing and e-scooter providers. These means of transport are in a rise in recent years and need assessment on viability.

In a second step, dynamic cost structures are built for these systems. Beginning with a Work Breakdown Structure (WBS), all cost drivers are displayed and categorized. Cost figures are found for all these categories before dynamically modelling them in *Excel*. As stated in the literature study already, the relocation and charging costs are the most challenging to model, since they are subject to stochastic usage and user patterns. The modelling of them is explained in greater detail in this chapter.

The cash flow table serves as basic tool to start the techno-economic analysis. The total discounted cost of the system over the entire time horizon can be calculated and converted to a total annual worth of the costs. The next step is to perform a sensitivity analysis on the different cost categories. By doing so, the most important categories or levers in the system will be highlighted. This is already a valuable output for current or future MSPs.

In a next step, more detailed analysis is performed, by controlling and varying well-chosen parameters. Different scenarios can be set up to resemble real-life cases. Scalability and other cost analysis can give insights into the cost structure in these different scenarios. Finally, when assuming a realistic and fixed demand input, break-even pricing can be performed. The pricing schemes of existing companies can be used to benchmark the obtained pricing and conclude about the viability of these companies. The generic work flow of the entire analysis is shown in Figure 3.1.

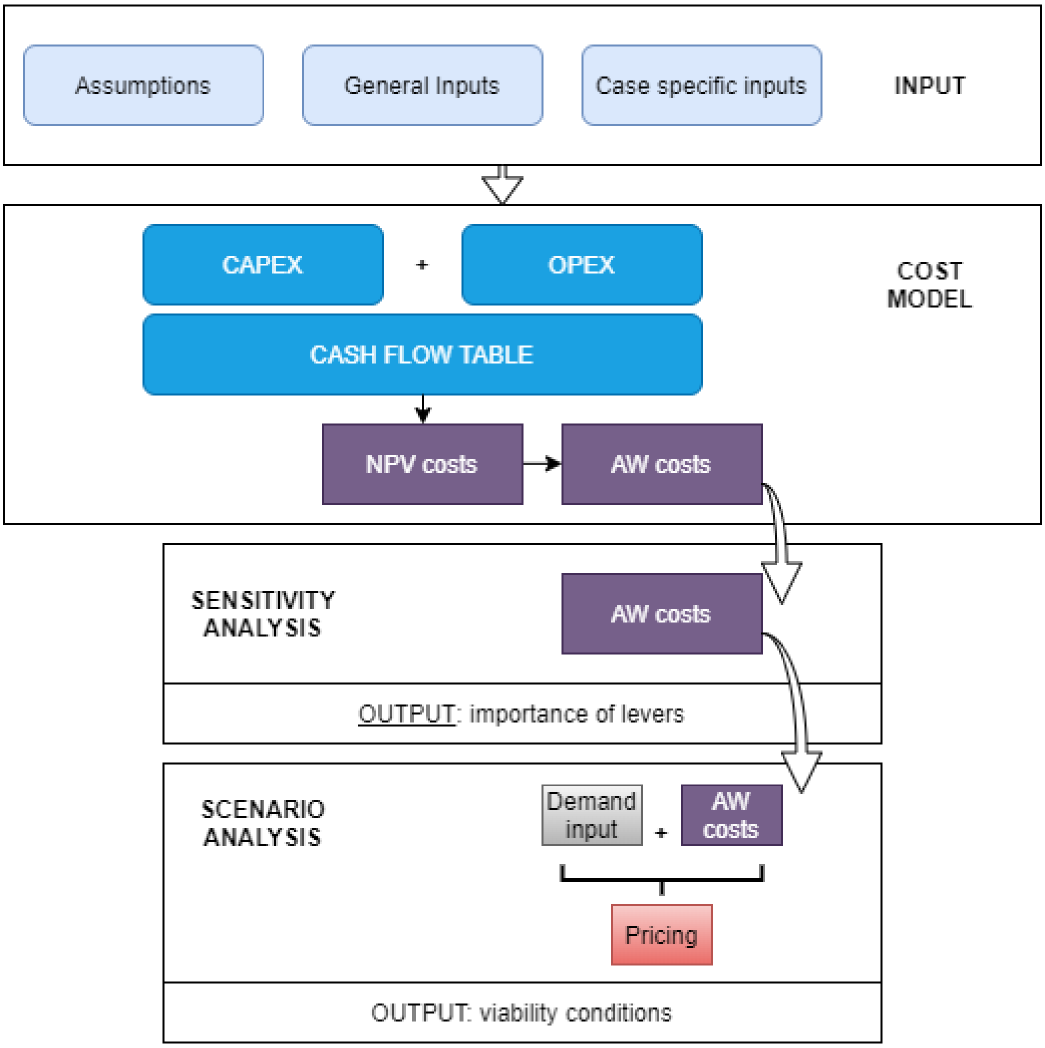


Figure 3.1: Generic flow of the analysis

3.1 Classification

In this section, the transport mobility providers will be classified into different categories. One way to do this could be based on the type of service that is offered. Five categories can be distinguished this way [5]. These are the membership-based self-service models, P2P self-service models, non-membership self-service models, for-hire service models or finally mass transit systems as depicted in Figure 3.2. Multiple types of transport modes occur within a single model. More traditional types like taxi services or PT that appear under the last two mentioned categories will not be incorporated in this classification.

Figure 3.2 gives a detailed overview of current available services. However, for this research, the type of service is of less importance to make the classification. In this project it was chosen to make the division primarily based on vehicle type and secondly on operational strategy. This way, each different model or category will require a new cost model to be built and investigated.

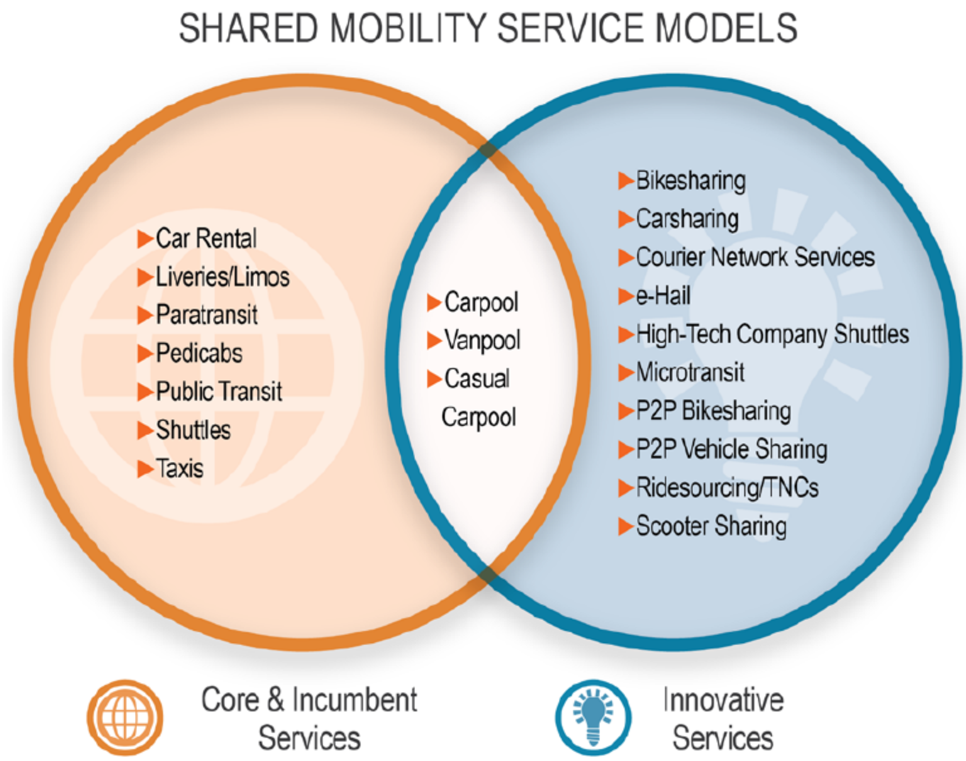


Figure 3.2: Core, Incumbent & Innovative Services [5]

The classification made in this project is shown in Figure 3.3. On the first level of the categorization a distinction is made between van/car, bike/e-bike, e-scooter and a category for all other types of vehicles. On the level below, distinctions are made based on service types and operational aspects. Properties and explanation of all categories are given in the next sections.

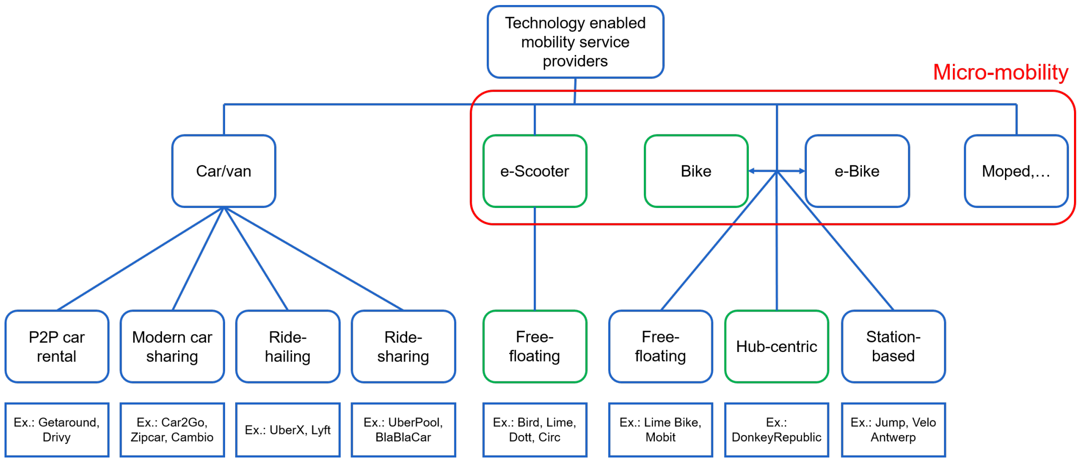


Figure 3.3: Classification of MSPs

3.1.1 Selection of providers for case study

From the overview in Figure 3.3, a subset of providers was selected to analyze in this research project. It was opted to perform the techno-economic analysis on two innovative services. More specifically hub-centric bike sharing providers and free-floating e-scooter providers.

As mentioned in the introduction, a lot of investments are being made in these new mobility service providers, while there is still great uncertainty on their business models. Nowadays shared bicycles and e-scooters are an image in cities that can't be unseen. By the simple nature of these vehicle types, their business models can be fairly modelled with decent estimates. A short note on the selected use cases is given below:

- **Hub-centric bike sharing provider**: As mentioned this shared bike system requires no great capital investments for building bike stations. Earlier studies have shown that they are overall cheaper and thus could have a more sustainable business model than the more traditional station-based systems. Their introduction in Belgian cities is fairly new and are for this reason innovative to evaluate.
- **Free-floating e-scooter provider**: Due to their massive appearance in cities last years and great uncertainty in economic feasibility, this model is most interesting to analyse. Several proposals for further improvements can be validated and assessed.

More important information on bike sharing and e-scooter sharing models is given in the next sections. This information is necessary in the method used, because they highlight operational aspects and differences between the models in a way that has an impact on constructing the cost model in the next step of the method. Further in this work, bike or scooter sharing will be referred to as explained here.

3.1.2 Bike/e-bike models

A bike sharing system or scheme is a service where bicycles are offered on the streets for shared use between individuals. Usually a price or fee per short term period is paid to unlock the bikes. The schemes have evolved over time by the evolution of different technologies. Currently, there is the division between docked systems and dockless systems as discussed below.

Station-based

This system consists of multiple bike stations deployed over the entire operational area. Bikes can be picked up at any station having one or more available bikes. Unlocking the vehicle normally takes place by use of a smart-card or with a personal code at the kiosk next to the station. Bikes can be dropped off at the end of the trip at any free stand of any station by locking it in. A typical station with kiosk can be seen in Figure 3.4.

Evidently, the amount of stations deployed over a city will have a major impact on the cost structure, both by capital investment as by maintenance. As discussed earlier, this system will also require a typical relocation strategy.

Figure 3.4: Bike station of *Vélo Antwerp*, Antwerp

Free-floating

More recent technologies have made it possible to eliminate the stations from the system and go over to a dockless system, also called free-floating (FF). Vehicles can be dropped off at any permissible location in the entire operational area. Because of issues of public space disorder in many cities where these systems are active, lots of precautions are taken already. These include restrictions to park a vehicle on the pavement, a maximum number of vehicles is allowed and so on.

The technologies that have enabled this system are GPS (Global Positioning System) integrated in an IoT (Internet of Things) solution. GPS-trackers are a necessary investment for the users to find a free bike and to be navigated to it. All kinds of data can be collected and transmitted to a central server by means of mobile connection. This data can be used to visualize and keep the customers up to date through their mobile app. Measuring and integrating all this data can be seen as an IoT-application. A huge amount of live data is processed by monitoring the use and location of all vehicles.

Hub-centric

A third way to organize the operations for a bike sharing system is called hub-centric. It is currently not specifically described in literature. *DonkeyRepublic* is an example of a provider in this category [6]. The hub-centric model uses designated parking locations for the pick-up and drop-off of the bikes. A hub is defined by a GPS point and a radius (e.g. 10 meters) around that point within which customers can drop off a bike. They can't end a rental unless they lock the bike within the delimited area, and there is a limited number of bikes that can be dropped off in that area.

Building a bike sharing system based on the hub-centric model does not require any of the expensive and space-demanding infrastructure such as docking stations. It also allows for a better control over the system for both operators and city authorities compared to a free-floating system, because they always know where the bikes are placed before and after a rental. The advantages of this system compared to the other two are shown in Figure 3.5.

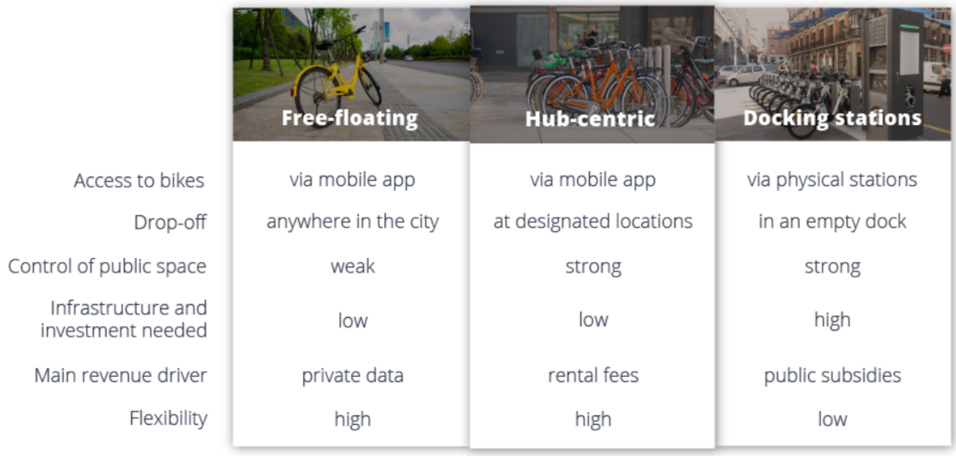


Figure 3.5: Features of the three bike sharing systems summarized [6]

3.1.3 e-Scooter model

Finally, the e-scooter model is discussed. E-scooters are a rather new means of transportation under the electrically driven mobility options. In 2018, the micro-mobility trend was re-energized with the emergence of the shared and dockless electric scooter (or e-scooter), pioneered by *Lime* and *Bird* in the U.S. [36]. In Europe, the word "step" is used more often. It is an electrically driven device, where people need to stand up and accelerate by means of turning a throttle by hand as seen in Figure 3.6.

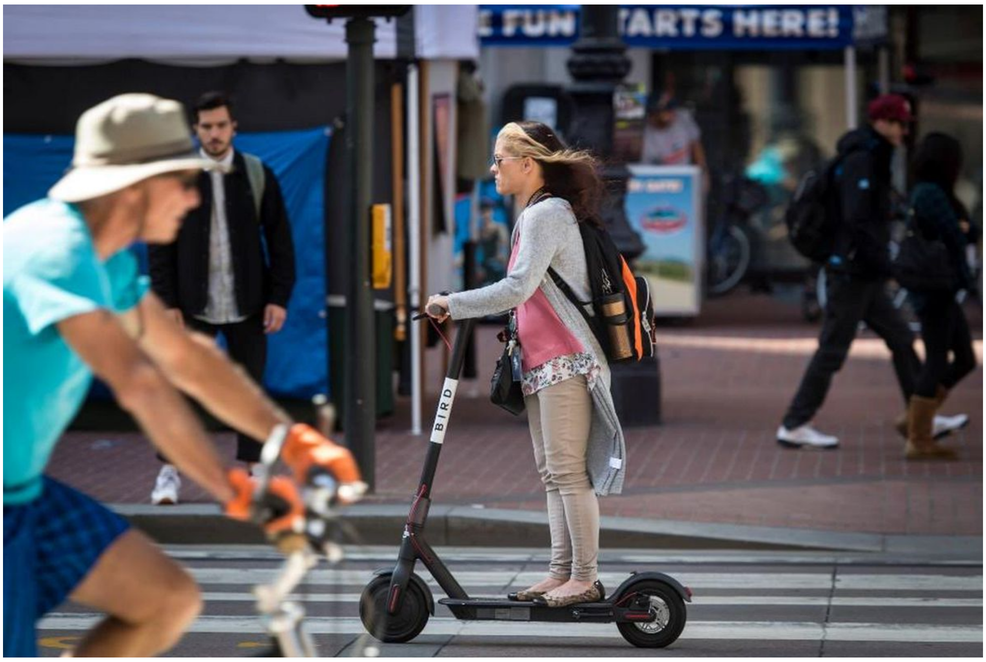


Figure 3.6: Woman making use of a shared *Bird* e-scooter

Evidently, one of the major costs related to this system that separates it from the others are the charging costs. There are four different operational methods that will be studied as exposed in Chapter 2. It is expected that changing method will have an important impact on the cost structure.

3.2 Building a cost model for micro-mobility providers

The first step in this techno-economic analysis is the construction of a cost model. Insights on scalability and importance of particular cost drivers can be discovered. Next, it will be used as input to perform a scenario analysis to derive the minimum viability conditions.

3.2.1 Cost modelling approach

It is chosen to start modelling using a work breakdown structure (WBS) [37]. Starting from the selected provider in the use case, the total cost of the system appears on level zero on top of the WBS tree. The categories on the first level are based on the categorization mentioned in the literature study, but slightly adapted for the ease of implementation. This classification gives a good overview and allows for better cost modelling. The categories are: platform, assets, operations, IT, administration and management & overhead. An overview of this WBS with all subcategories can be seen in Figure 3.7. By filling in the WBS in a bottom-up way, the total cost of the system can be estimated.

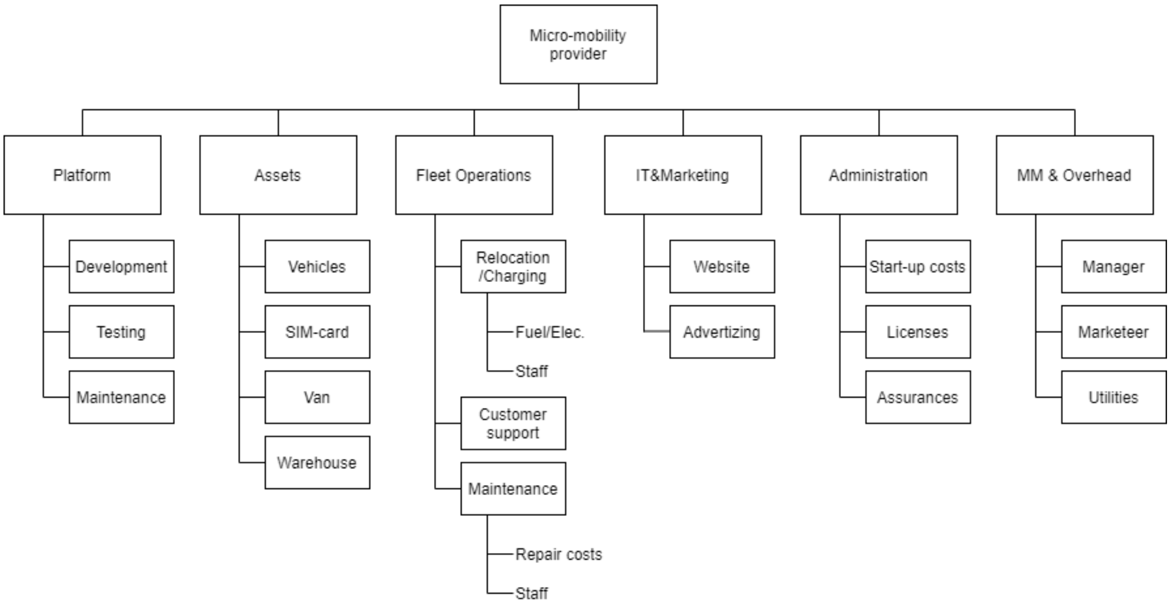


Figure 3.7: General WBS for micro-mobility providers

The costs can further be classified into capital and operational expenses as done for evaluating an operational business case. This is necessary to convert the cost structure into a dynamic cost model. Capital expenses, referred to as CapEx, are defined as the costs needed for the development or supply of non-consumable parts of a product, system or investment. Operational expenses, or OpEx, are the recurring costs that a business incurs through its normal business operations, these could include insurances, wages, inventory costs, etc. It is important to notice that the investment in the necessary vehicles is viewed as twofold in this project. In the phase before deploying the system, a fleet of vehicles needs to be bought and this is seen as a CapEx, while the replacement of stolen or damaged vehicles is seen as OpEx. To make this division more clear, CapEx and OpEx will be referred to as of here by one-off costs and recurring costs respectively. A second classification of the costs that can be made while cost modelling is the division into fixed and variable costs. Fixed costs remain the same no matter the output of the system, while variable costs change with the amount produced or bought. A division of all costs based on these two properties is given in the cost matrix in Figure 3.8.

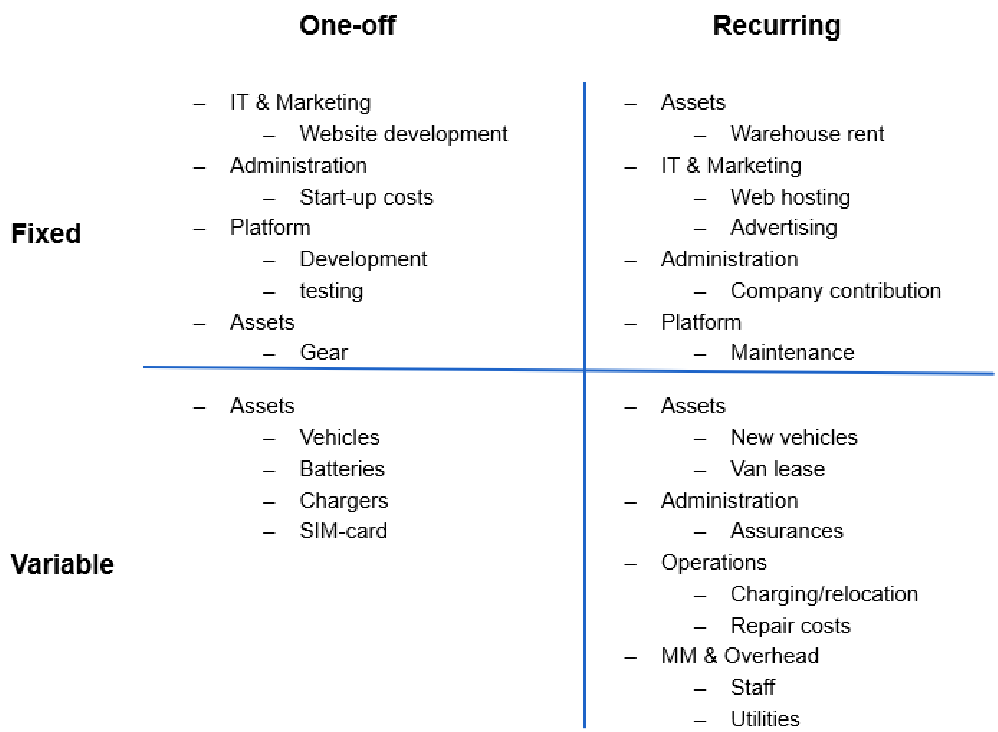


Figure 3.8: Cost matrix

A last aspect of the cost model is that it should be time-variant, as the long-term viability conditions are under investigation. Estimation of the costs over this time period should be found. Most of the costs are found by performing desk research on existing systems, online wholesale prices, newspapers and technology blogs. The estimations of all costs that are used as data input in the model are given in the next sections.

The cost modelling was done in *Excel*. It was most important to make it as a dynamic model to be able to adjust parameters and make different scenarios. Outputs like the amount of vehicles to replace each month and the associated costs are dynamically calculated using the input data.

3.2.2 Assumptions and data input

The input data is divided into three categories for clarification. The first category are the general modelling assumptions that are used for all cases. Secondly, there are generic inputs for both cases. These are for example cost estimations that are the same for both cases, such as utilities costs. Thirdly there are case specific inputs, such as the purchase prices of the different vehicles.

3.2.2.1 General assumptions

The general assumptions are needed to make the cash flow tables. A time horizon of five years is chosen. This is similar to the bike sharing studies discussed in the literature study.

Price increase over the years is reflected in the cash flow table by applying an inflation factor of 2%. This is the targeted inflation and Belgian average [38]. Costs (and revenues) that occur in the future are discounted with a discount rate of 15%. The net present value (NPV) can be calculated with the discounted costs. The modelling assumptions are listed in Table 3.1.

There are some other modelling assumptions that have to be made in order to calculate the total cost of the systems. An example of this is the amount of vehicles in the system. However, such assumptions are scenario specific and will be given in the results section where different real-life scenarios are evaluated.

Assumptions		**unit**
Time horizon	5	years
Discount rate	15	% (annual)
Inflation rate	2	% (annual)

Table 3.1: General assumptions

3.2.2.2 Generic input for both cases

The generic inputs that can be used for both the bike sharing and e-scooter model are mainly unit costs and staff costs and are listed in Table 3.2.

Inputs	**Amount**	**unit**	**reference**
Gear	10.000	€	Assumption
Web design	5.000	€	[39]
SIM subscription	21	€/card	[40]
SIM card	2,5	€/card	[40]
Van lease	455	€/van/month	[41]
Web hosting	200	€/year	[39]
Social media	200	€/month	Assumption
Company contribution	350	€/year	[42]
Start-up costs	1.500	€	[42]
Licenses	0	€/year	Assumption
Fuel consumption	0,13	l/km	[41]
Fuel cost	1,35	€/l	Assumption
Utilities cost	0,3	€/m²	Assumption
IT developer wage cost	50	€/h	Assumption
Manager wage cost	60	€/h	Assumption
Other wage cost	40	€/h	Assumption

Table 3.2: Generic input parameters for both cases

3.2.2.3 Specific input for bike sharing providers

Some costs only occur in the case for the bike sharing providers and are listed in Table 3.3. It must be noted that the total cost of a shared free-floating bicycle is calculated as the sum of the wholesale price of all components that are needed to assembly such bike according to the guidelines of *DonkeyRepublic* [43].

The software estimation cost is done by the historical analogy estimation method [44]. In this method, the cost is estimated based on a similar project from the past. It was chosen to base the comparison on a well-described *Uber* case in which the amount of development hours are listed [45]. The amount of testing hours is taken as 35% of the development hours as the average percentage division of software development work prescribes [46].

Inputs	**Amount**	**unit**	**life expectancy**	**reference**
Bikes	100	€/bike	2 years	[47],[48]
Locks	50	€/lock	4 years	[49]
Batteries	2	€/battery	2 years	[43]
GPS tracker	15	€/tracker	4 years	[50]
Warehouse rent	3,75	€/m^2/month		[51]
Insurances	28	€/bike/year		[52]
Repair costs (material)	2,5	€/bike/month		[53]
Platform costs	157.680	€		[45]

Table 3.3: Specific input parameters for bike sharing provider

3.2.2.4 Specific input for e-scooter sharing providers

Some costs only occur in the case for e-scooter providers. These are listed in Table 3.4. The production price for the vehicles is assumed to be for ready-made and sharing-proof e-scooters equipped with all the needed IoT devices such as a built-in GPS tracker. A distinction is made between the purchase price for a normal scooter that is used in operational models option 1, 2 and 3 as described in the literature study on the one hand-side, and a scooter that can be equipped with a swappable battery as needed in operational model option 4. This is indicated between brackets in Table 3.4.

The warehouse rent price is taken a little more expensive than in the bike sharing case, because it will be assumed that these warehouses are located in the city centre. While in the bike sharing case it is opted to rent a warehouse outside the city for trade-off reasons between rent price and fuel consumption. Insurances are taken a little higher as well because of the higher purchase price of the vehicles.

Inputs	Amount [€]	unit	life expectancy	reference
e-Scooters (1,2,3)	500	/scooter	2 months	[54],[27]
e-Scooters (4)	405	/scooter	2 months	[54]
Swappable batteries (4)	95	/battery	1 year	[55]
Chargers	18	/charger	2 years	[56]
Warehouse rent	7	/m^2/month		[51]
Insurances	50	/bike/year		Assumption
Repair costs (material)	23	/scooter/month		[57]
Electricity price	0,2	/kWh		[58]
Payment fees	0,05	/trip		[54]

Table 3.4: Specific input parameters for e-scooter sharing provider

3.2.3 Relocation cost modelling

Relocation costs are the most complex cost to modelling because of the dynamic and stochastic behaviour of the rebalancing needs. As discussed in the literature study, there are two common strategies. In the dynamic relocation strategy, rebalancing needs are monitored the entire day and based on a stochastic model, multiple rebalancing trips are scheduled during the day. The service level obtained with this strategy is generally high, but the costs are significant as well because of the extra efforts in multiple trips. In the static case, rebalancing is performed during fixed time slots, for example two times a day. It is opted to make a cost estimation for static relocation costs in the remainder of this project, because active providers show resemblances to this type of strategy.

Besides the choice for a static relocation strategy, some other model assumptions have to be taken into consideration. The size of the operational area, the amount of bikes, the amount of stations deployed over the city and the demand pattern have an impact on the relocation needs. The next section explains the assumptions that are made for these parameters and how they are dealt with in the relocation model.

3.2.3.1 Assumptions on relocation input parameters

When designing a bike sharing system, a decent consideration or even optimization needs to be performed on three choices. These are firstly the total fleet size on the one-hand side, and the amount of stations on the other. Note that the hub-centric model is considered as a station-based system in the context of relocation, because the geofenced hubs are nothing more than a bike station without any infrastructure. The third choice that should be made is the relocation strategy. The input parameters for these optimizations are the area size and the potential demand in the system.

Demand

The demand could in the first place be related to the population density of a city. Other factors are the social balance in a city, the touristic importance, availability of alternatives (like PT), availability of bike-friendly infrastructure and the topology of the city. These factors together will have an influence on the daily demand and usage patterns, which are stochastic. However, for the aim of this research it is not necessary to over-complicate the modelling with dynamic demand patterns. A continuous approximation of the demand by assuming a uniform average demand level will suffice [59]. The most convenient metric is to express the demand as trips/bike/day.

Fleet size and station density

The ITDP [60] prescribes a station density of 10-16 stations per squared kilometer for a good user uptake. Their recommendation for the fleet size is to have 10-30 bikes per 1000 residents. This ratio should be large enough to meet demand, but not so large as to have fewer than four daily uses per bike. They also state that the bike density (amount of bikes per squared kilometer) is a more useful and accurate picture of how bikes are spread across a city.

Using these recommendations it was opted to relate both fleet size and station density to the area size of the considered operational area. These parameters are estimated, by performing a linear regression on available data of eleven existing systems worldwide [61, 62, 63]. The results indicate a relationship of 6 stations per squared kilometer and an average of 12 bikes per station. The regression plots are shown in Figures 3.9 and 3.10.

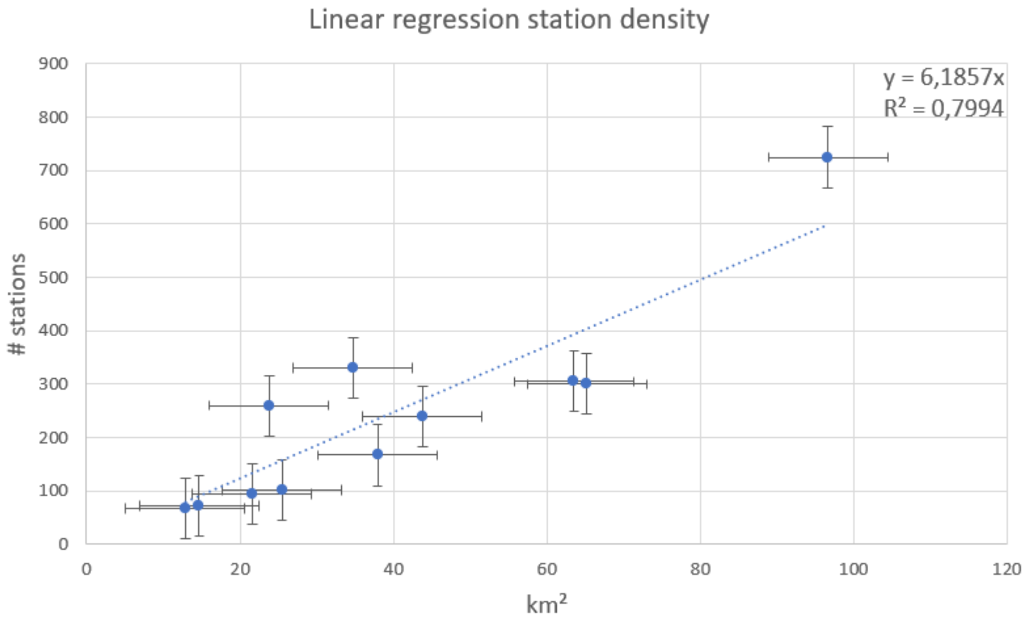


Figure 3.9: Linear regression on station density

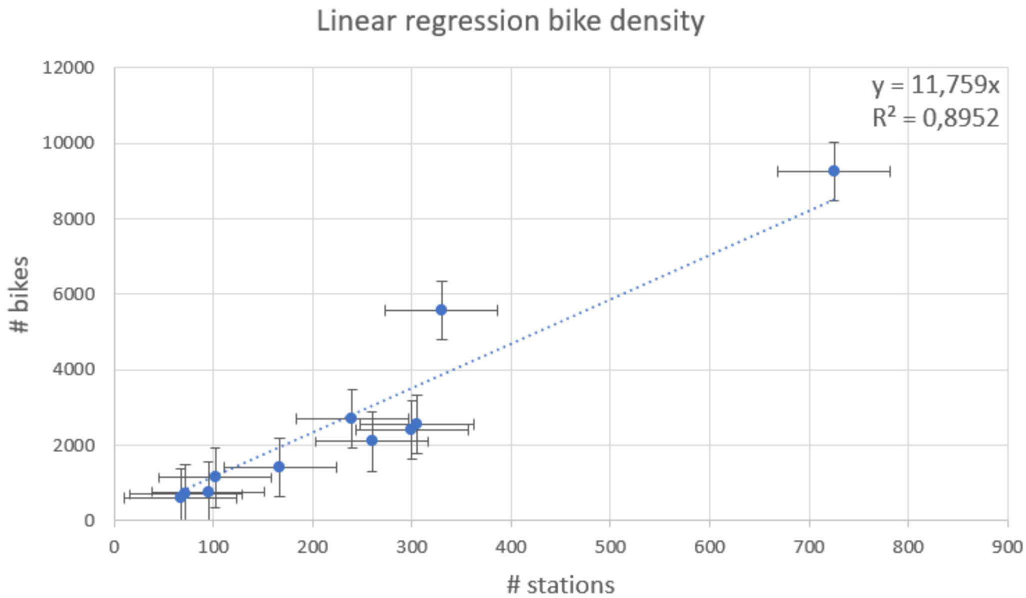


Figure 3.10: Linear regression on bike density

Relocation strategy

The chosen relocation strategy is static rebalancing. Rebalancing operations will be performed two times a day during shifts. The problem can be interpreted as a variation on the classical vehicle routing problem (VRP), namely the pick-up and delivery problem (PDP). In a PDP, a set of routes has to be constructed in order to satisfy transportation requests. A set of vehicles with a given capacity need to transport loads from a given set of origins to a specified set of destinations [64]. Applied to the relocation of the vehicles, a van starts at a central warehouse and arrives at the first pick-up station, where it picks up the load (amount of vehicles that need to be relocated) and transports them to their destination (station with low bike density). Considering the amount of work and time this takes, one van or employee can perform multiple rebalancing operations within the time slot of the shift.

The costs that are considered in the calculation of the relocation cost are fuel costs and wage costs. In order to calculate them, an estimation of the above-mentioned PDP tours needs to be made. In the available academic literature on relocation strategies, there is one study that gives estimates on these numbers [62]. For a static case with 2 shifts per day, an average of 90 kilometers per trip is driven in a city of 35 km^2. This value will be used as a benchmark in the form of a distance rate, by expressing it as $[km/km^2]$. The strategy can be summarized as follows:

- Relocation strategy: static
- Amount of shifts per day: 2
- Distance rate: $90km/35km^2 = 2,57km/km^2$

It must be noted that this distance rate benchmark assumes a linear relationship between the area size and the relocation trip length. Larger cities will thus require larger relocation operations. The assumption of a linear relationship can be justified by looking at the modelling parameters from the benchmark study. It reported a total amount of 280 stations in an area of 35 km^2, which comes down to a station density of 8. This is in line with the linear regression performed on the station density of other existing systems. Because of the linear relationship between the amount of stations and the area size, it is justified to assume a linear relationship between the relocation tour length and the area size as well.

Speed

The estimation of the total distance to be covered per relocation shift will be the starting point for the cost calculation. To calculate the wage cost, the total distance per day needs to be converted to the total time needed to perform the relocation. Consequently the amount of relocation hours together with shift length will result in the number of employees to hire. This number will be a first validation for feasibility of the model.

It is logical to take the speed as conversion factor. However, a correct estimation of the speed by which relocation is performed, is critical. Thirty samples are taken from *Google maps* that represent typical movements between two stations [65]. They are listed in Table 3.5. Each sample shows the speed for typical relocation movements between two stations. The assumption is made that 50% of the time a relocation vehicle is moving with this average speed and 50% of the time it is standing still loading and unloading the bicycles. This results in a conservative average speed of 10 km/h. Because the central warehouse is located outside the city centre, an average speed of 50 km/h is assumed for the distance covered to reach the operational area.

Nr.	**Speed [km/h]**	**Nr.**	**Speed [km/h]**
1	12,6	16	22
2	27,7	17	15
3	24,8	18	21,6
4	21,8	19	26,5
5	24	20	11,3
6	22	21	26
7	24,8	22	22,6
8	27	23	25,2
9	16,5	24	21,3
10	21	25	18
11	25,5	26	18,8
12	19,5	27	19,2
13	24	28	19,7
14	15	29	19
15	16	30	18
Average speed = 20,9 km/h			

Table 3.5: Estimation of the average relocation speed

3.2.3.2 Cost calculation

Now that the most critical input parameters have been discussed and estimated, the calculation of the total monthly relocation cost can be done. All necessary input parameters are listed in Table 3.6. It must be noted that these are temporarily set at these values and can be changed in other scenarios. The relocation model had 3 iterations of refinement after proper analysis of the parameters. The final is model explained below together with a sensitivity analysis on the results.

Parameter	**Value**	**unit**
# relocation trips/day	2	trips/day
# relocation days/month	20	days/month
Area size	23,5	km²
Distance to depot	20	km
Fuel cost	0,17	€/km
Wage cost	40	€/h
Distance rate	2,57	km/km²/trip
Relocation speed	10	km/h
Approach speed	50	km/h
Length of shift	4	h

Table 3.6: Relocation model: input parameters

As explained earlier, the relocation cost is composed of a fuel cost part on the one-hand side, and a wage cost for the employee performing the operations on the other. Costs for leasing a van are categorized as an asset cost. Some symbols for the input parameters and costs are introduced int Table 3.7 to be used in the expressions for the calculation of the total daily cost.

Before calculating the different costs, some extra parameters need to be derived from the input parameters. Considering the fuel cost, the total amount of kilometers driven need to be known and is calculated as follows:

$$\begin{aligned} K_{td} &= (K_{cc} + K_{oc}) * r_d \\ &= (A * d_r + 2 * d_d) * r_d \end{aligned}$$

The amount of kilometers driven are converted to a total amount of hours needed per shift to perform the relocation operations:

$$H_s = K_{cc}/v_r + K_{oc}/v_a$$

The amount of hours needed are not simply multiplied by the hourly wage cost to obtain the total wage cost. It is more realistic to assume a fixed amount of full-time employees

Symbol	Description	Symbol	Description
r_d	Amount of relocation trips per day	TC_m	Total monthly relocation cost
n_m	Amount of working days per month	TC_d	Total daily relocation cost
A	Area size (km^2)	C_F	Daily fuel cost
d_d	Distance from depot to city centre (km)	C_W	Daily wage cost
c_f	Fuel cost (eur/km)	F_{TE}	Amount of FTEs to employ
c_w	Wage cost (eur/h)	W_d	Daily wage cost
d_r	Distance rate (km/km^2/trip)	K_{td}	Total amount of kms driven daily
v_r	Relocation speed (km/h)	K_{cc}	Kms driven per shift in city centre
v_a	Approach speed from depot to city centre (km/h)	K_{oc}	Kms driven per shift outsice city centre
s_l	Shift length (h)	H_s	Daily hours needed to perform relocation

Table 3.7: Symbols used in relocation cost calculations

(FTEs) to hire to perform the relocation operations. The amount of FTEs is obtained by rounding the division between the hours needed per shift and the shift length. By implementing a buffer of 0,5 hours in the shift length, rounding can be safely done either upwards or downwards:

$$F_{TE} = \lceil \frac{H_s}{s_l - 0.5} \rfloor$$

A last parameter that has to be calculated is the daily wage cost for one FTE:

$$W_d = r_d * s_l * c_w$$

The total daily relocation cost can now be calculated as the sum of the daily fuel and wage cost as follows:

$$\begin{aligned} TC_d &= wagecost + fuelcost \\ &= C_W + C_F \\ &= F_{TE} * W_d + K_{td} * c_f \end{aligned}$$

Finally, the total monthly cost is calculated by multiplying the daily relocation cost by the amount of days performed.

$$TC_m = n_m * TC_d$$

3.2.3.3 Sensitivity analysis on relocation model

Unfortunately, the total cost of relocation could not be validated by the figures of an existing company due to lack of cooperation. To help validating the model somehow, a thorough sensitivity analysis is performed on the most critical parameters. The most important levers of the relocation model could be exposed this way.

First of all, the total daily relocation cost was set out against a varying size of the operational area. The total cost was decomposed into its primal building blocks, being fuel and wage costs in Figure 3.11. It is noticeable that the total cost is almost entirely due to wage costs. Therefore, fuel costs are almost negligible in the model. It could be concluded from this analysis that an estimation of the relocation costs is equivalent to estimating the right amount of FTEs to employ. The plot shows that for increasing operational areas, the amount of FTEs goes from 1 to 4, which is very realistic in this scenario.

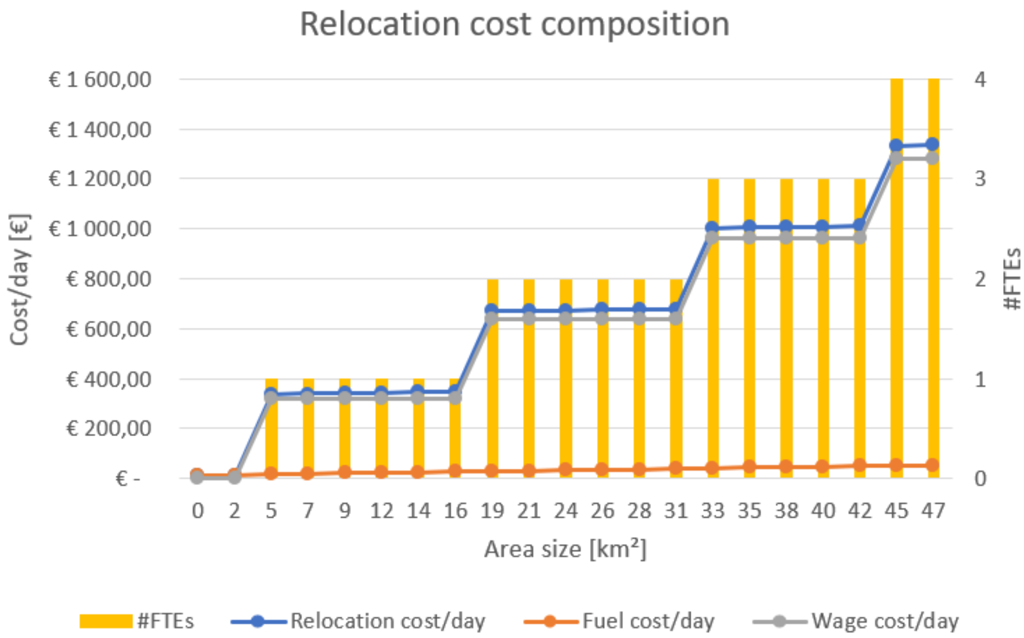


Figure 3.11: Composition of daily relocation cost

To further check the accuracy of the model, sensitivity analysis was done on the most critical parameters, being the depot distance, the distance rate and the speed. Figure 3.12 displays the sensitivity of these factors on different sub-parts of the relocation cost. From figure 3.12a it can be seen that there is a robust area around the base case value at 0%. The depot distance and approach speed do not effect the total relocation cost. This observation was hoped for and is a confirmation of decent modelling. The same conclusions can be drawn for the sensitivity on the amount of hours and FTEs, as it was earlier observed that the total relocation cost was almost entirely due to wage costs.

The conclusion that can be drawn from this sensitivity analysis is that a realistic and safe estimation can be modelled. Bottom-line, it comes down to choosing the amount of FTEs to employ. The amount of FTEs that the model generates seems realistic and further conclusions in the analysis will be made under the assumption of this important estimation.

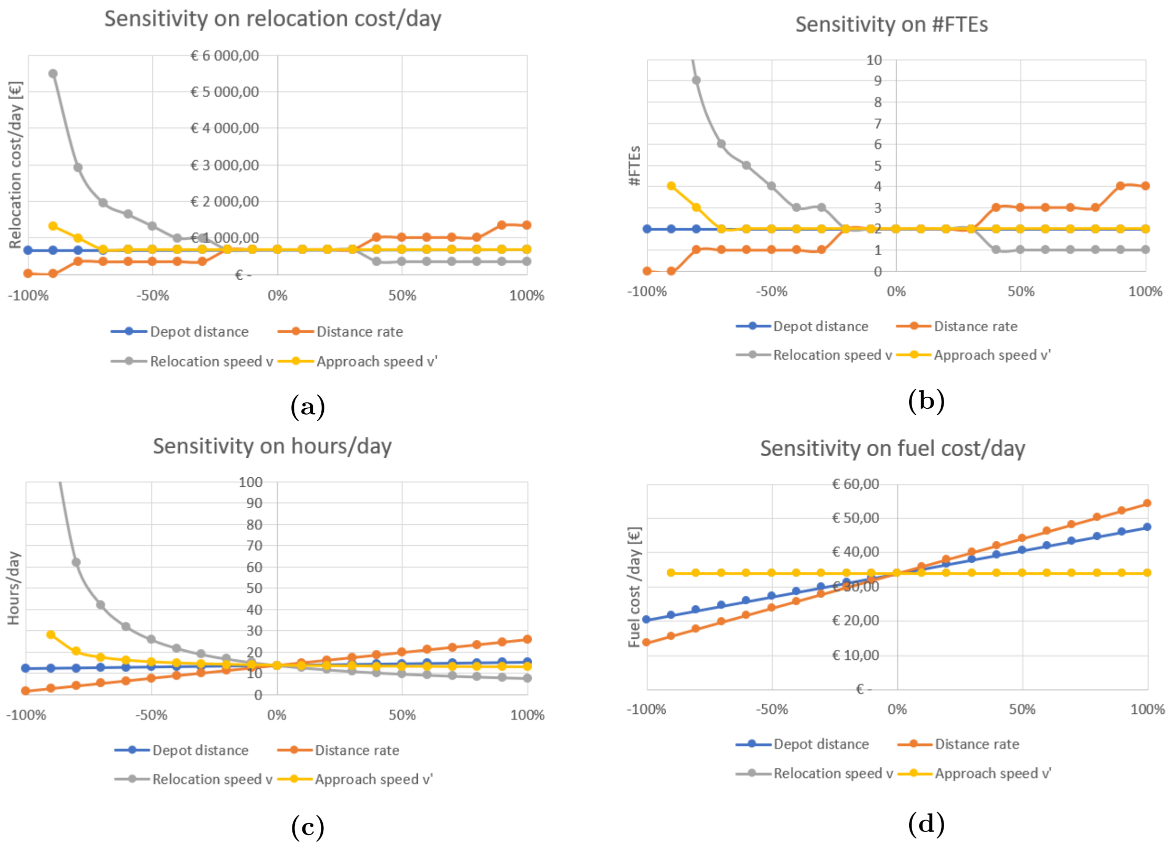


Figure 3.12: Sensitivity analysis on relocation cost model

3.2.4 Charging cost modelling

For e-scooter sharing providers, one of the main operations is the charging of the electrical vehicles. There are some main inputs for all four models that are related to demand parameters and general battery characteristics. Starting from this general input, four different charging cost models are constructed to calculate what is considered as the monthly charging costs. As in the relocation cost model, the cost of leasing vans is not incorporated, because it is considered as a recurring cost in the assets category. The charging cost is implemented as the sum of the electricity costs to charge the e-scooters, fuel costs for the relocation vehicle and of course wage costs.

The assumptions and how the charging cost models are built, are explained in the next sections. A sensitivity analysis on the most critical input parameters is performed again to help validating the output.

3.2.4.1 Assumptions on charging input parameters

There are several important factors that have an impact on the monthly charging costs in the following model. These are the relocation vehicle speed, demand input, battery characteristics, charging alert and the estimation of the round-trip length to perform a charging tour. They are discussed below.

Demand

First of all, the charging need is incurred by the battery consumption while the vehicles are in use and some continuous consumption that is inherent to batteries. Therefore, the demand input has to be known in order to calculate the daily battery consumption. Research from existing systems indicate an average of 3 rides per scooter per day. The demand input parameters are listed in Table 3.8 for this validation, they can be different in other scenarios.

Demand input parameters	Amount	Unit
Time duration/trip	18	min
Distance/trip	2,8	km
#trips/scooter/day	3	

Table 3.8: Demand input parameters charging model

Battery characteristics

Other assumptions that have to be made are on the battery characteristics. Parameters needed to calculate the charging need for a typical lithium-ion battery used in e-scooters are given in Table 3.9.

Parameter	Amount	Unit
Power	300	W
Elec. Potential	36	V
Elec. Current	13	Ah
Max capacity	468	Wh
Charging time	4	h
Max range	30	km

Table 3.9: Battery characteristics

Charging alert and frequency

All e-scooters are equipped with smart sensors that can rise an alert in the digital management system when the vehicles are in need of charge. To ensure a reasonable degree of service level, risk of batteries being completely empty should be avoided. Taking into consideration that the batteries can lose power overnight, the assumption is made that a charge alert is raised in the system when battery level reaches 40%. When assuming a charging efficiency of 93%, the total amount of charging need (Wh) can be easily calculated. These parameters are listed in Table 3.10

Alert parameters	Amount	Unit
Max capacity	468	Wh
Charge alert	40%	
Chargers efficiency	93%	
Charging need	302	Wh

Table 3.10: Charging alert and need

Besides the amount to be charged each time, it should be known how often an e-scooter appears in need of charge. The charging frequency can be easily calculated from the demand input and charge alert level of 40% using the following calculations. The numeric results are shown in Table 3.11. The charging frequency per day of 0,5 means that a scooter needs to be charged every two days.

$$\begin{aligned}
\text{Amount of km's/vehicle/day} &= \text{(Amount of trips/vehicle/day)*(km's/trip)} \\
\text{Amount of km's until charge needed} &= (1 - 40\%) * \text{max range} \\
\text{Charging frequency/day} &= \frac{\text{Amount of km's/vehicle/day}}{\text{Amount of km's until charge needed}}
\end{aligned}$$

Frequency parameters	Amount
#kms/veh/day	8,4
#kms until charge needed	18
Charging frequency/day	0,5

Table 3.11: Charging frequency calculation

Charging tour length and load

An estimation should be made on the tour length. It is the amount of kilometers driven to perform the charging operations, starting from the decentralized hubs in the city centre. A description of those tours for the four different options is listed below:

- **Option 1: In-house pick-up**: The in-house employees start from the hubs with an empty van, reaching out in the city to collect the first scooter in need of charge. It continues its tour to collect the remaining scooters until its van load is reached and returns to the hub. This is one charging tour. In the morning, similar tours are performed to redistribute the charged scooters over the city.
- **Option 2: Gig workers**: Charging is performed by gig workers and thus no cost related to a tour length should be calculated.
- **Option 3: Combo**: This is a combination of option 1 and 2. The vehicles that are charged with option 1 are collected with similar tours as explained with option 1.
- **Option 4: Battery swaps**: The in-house employees start from the hubs with an empty van, but loaded with a maximum load of charged, swappable batteries, reaching out in the city to the first scooter in need of charge. There it swaps the batteries and continues its tour to the remaining scooters in need of charge. Damaged scooters can be taken in the van, but this does not affect the tour length.

It was opted to calculate the tour length by introducing two variables. The first one being a lump sum distance to reflect the need of reaching out to the farthest located scooter in the beginning of the tour. A safe and conservative choice was made to set this value at 2km. Secondly, an intra-scooter distance is chosen to reflect the distance traveled between two consecutive scooters on the tour. An intra-scooter distance of 0,5km was chosen. This is a rather conservative estimate, but realistic as well since scooters can be parked anywhere. The amount of scooters that can be loaded in the van for options 1 and 3 are typically 20. The amount of swappable batteries transported in option 4 is set at 30, because they take less space, but leaving some space for possible damaged scooters to collect. These parameters are listed in Table 3.12.

Tour parameter	**Amount**	**Unit**
Lump sum distance/tour: L	2	km
Intra-scooter distance: d	0,5	km
Max van load (1, 3): v_1	20	scooters
Max van load (4): v_4	30	batteries

Table 3.12: Charging tour length parameters

The tour length is than easily calculated as follows:

$$\text{Tour length} = L + d * v_i$$

3.2.4.2 Cost calculation

Now that the most critical input parameters have been discussed and estimated, the calculation of the total monthly charging cost can be done. All necessary input parameters plus the ones discussed and calculated above are listed in Table 3.13. The charging model had 3 iterations of refinement as well after proper analysis of the parameters. The final model is explained below together with a sensitivity analysis on the results. An important note is made on the costs of option 3.

Charging model parameters	**Amount**	**Unit**
Fleet size	300	scooters
Fuel cost	0,17	€/km
Electricity price	0,2	€/kWh
Wage cost	40	€/h
Relocation speed	8,5	km/h
Lump sum distance/tour	2	km
Intra-scooter distance	0,5	km
Shift length	4	h
Charging frequency	0,5	scooters/day
Charging need	302	Wh
Tour length (1,2,3)	12	km
Tour length (4)	17	km

Table 3.13: Charging model input parameters

The charging cost will be interpreted as the sum of electricity costs, fuel costs and wage costs for employees performing the charging. Extra symbols for the above-mentioned parameters and cost calculations are given in Table 3.14. The calculations for the four options are explained below.

Symbol	Description	Symbol	Description
N	Total fleet size	n_m	Amount of working days per month
c_f	Fuel cost (€/km)	TC_m	Total monthly charging cost
p_e	Electricity price (€/kWh)	TC_d	Total daily charging cost
c_w	Hourly wage cost	C_F	Daily fuel cost
v	Relocation speed (km/h)	C_W	Daily wage cost
d	Round-trip length of one charging tour	C_E	Daily electricity cost
s_l	Shift length (h)	H_t	Amount of hours needed per charging tour
P_c	Charging need per scooter (Wh)	T_o	Amount of tours an operator can do per shift
f_c	Charging frequency	B_o	Amount of bikes an operator can charge per shift
N_c	Amount of vehicles to charge each day	F_{TE}	Amount of full-time employees needed to perform charging
l	Max load of relocation vehicle		

Table 3.14: Charging cost calculation symbols

Before calculating the different costs, some extra parameters need to be derived from the input parameters. The amount of vehicles to charge is not equal to the total fleet size in this charging model. It is calculated by the multiplication of the total fleet size and the previously calculated charging frequency:

$$N_c = f_c * N$$

To start with, the obtained tour length can be converted into the amount of hours needed to perform such round-trip tours. Based on this value, together with the shift length, the number of milk runs per operator per shift can be calculated. By multiplying this value with the load of the van, the total amount of bikes an operator can charge in a shift is obtained. This will permit to derive the amount of FTEs needed to perform the charging operations. The calculations are shown below:

$$
\begin{aligned}
H_t &= d/v \\
T_o &= \lceil \frac{s_l - 0,5}{H_t} \rfloor \\
B_0 &= T_o * l \\
F_{TE} &= \lceil \frac{N_c}{B_o} \rfloor
\end{aligned}
$$

The total daily charging cost can now be calculated as the sum of the daily fuel cost, wage cost and electricity costs as shown below. It must be noted that the multiplication with the factor two only holds for options 1 and 3 where scooters are picked up by in-house employees. This is done because the e-scooters are redistributed in the morning. For option 4, operating with battery swaps, only one shift per day is needed and the multiplication with two should be omitted in the calculations.

$$
\begin{aligned}
TC_d &= electricitycost + wagecost + fuelcost \\
&= C_E + C_W + C_F \\
&= P_c/1000 * p_e * N_c + F_{TE} * s_l * c_w * 2 + d * T_o * F_{TE} * c_f * 2
\end{aligned}
$$

Finally, the total monthly cost is calculated by multiplying the daily charging cost with the amount of days performed. This value is set at 30, because charged e-scooters should be available every day.

$$TC_m = n_m * TC_d$$

3.2.4.3 Sensitivity analysis on charging model

Again, the total cost of charging could not be validated by figures of an existing and operationally active company due to lack of cooperation. Sensitivity analysis is performed on the most critical parameters to show the correctness and accuracy of the model. It is opted to choose for a more conservative estimate for the most critical parameters.

The total charging cost is dependent on the amount of trips made each day. Therefore, an estimate of the cost can only be made if a specific scenario, with a fixed fleet size, is selected first. The amount of vehicles in this analysis is set at 300 in the base case. A first analysis was done to check the effect of changing this fleet size on the daily charging cost per vehicle. It must be noted that 'per vehicle' in this value means 'per vehicle charged', because not all vehicles need charging every day. The results are plotted in Figure 3.13.

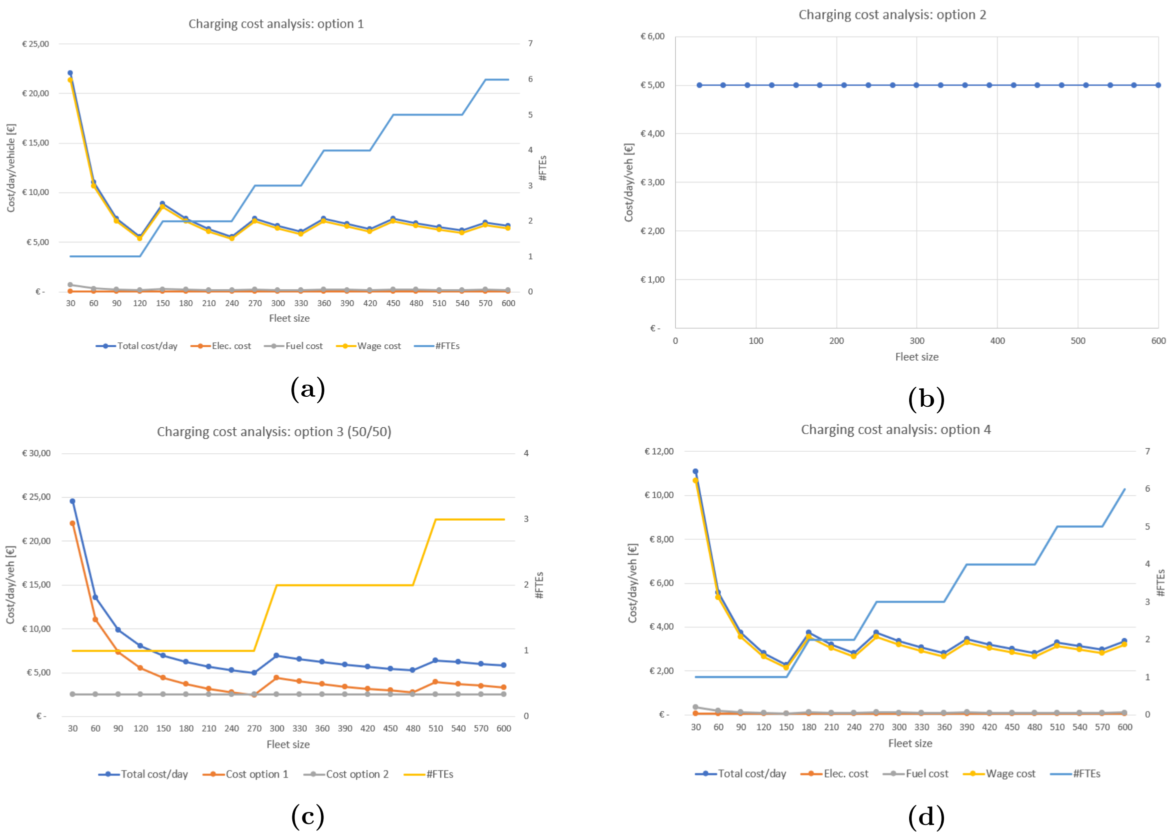


Figure 3.13: Composition of charging cost/day/vehicle for the four options

For option 2 it is obvious that the cost per vehicle per day does not change with varying fleet size, since a fixed cots per charged vehicle is paid to a gig worker. In the other two pure strategies, options 1 and 4, it can be seen from Figures 3.13a and 3.13d that almost the entire charging cost is due to wage costs. This makes sense because charging one vehicle only costs about 6 cents in electricity consumption and fuel costs are kept low as in the relocation model. More caution should be taken with the interpretation of the results of option 3 in Figure 3.13c. It indicates that option 1 is more expensive to use than option 2. The total cost per vehicle per day of all four options are plotted together in Figure 3.14.

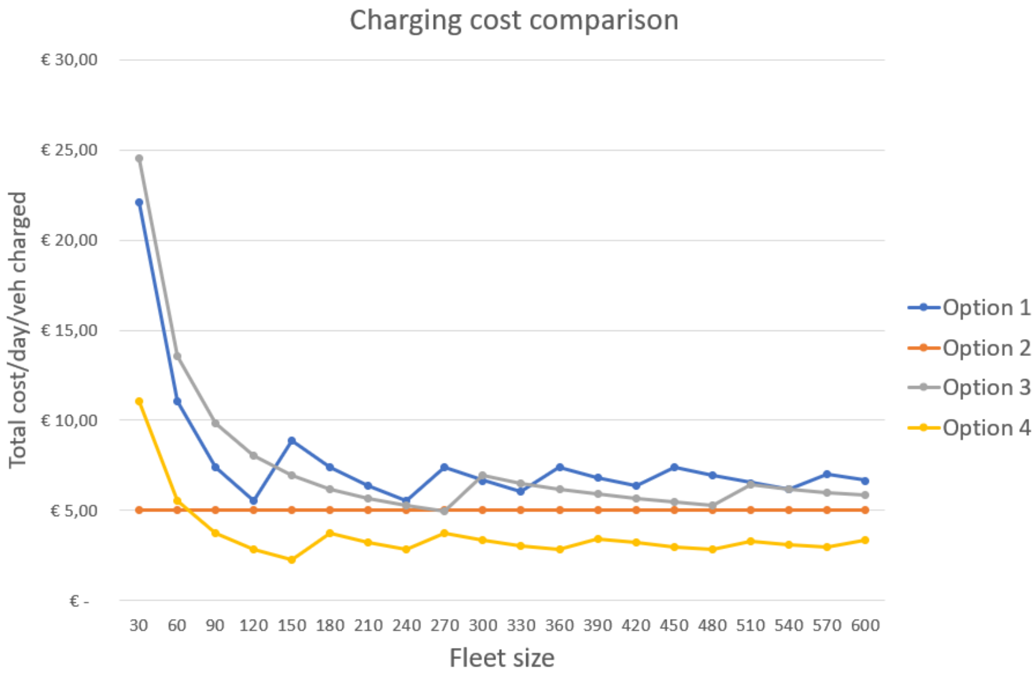


Figure 3.14: Comparison of charging options

Without going too detailed into the discussion on the comparison of the costs, which is content for a later chapter, a note should be made on the cost curve of option 3. It seems strange at first sight that option 3 is sometimes cheaper and sometimes more expensive than option 1. One would think that substituting a proportion of the workload in option 1 with the cheaper option 2, would result in an overall lower option 3 cost compared to option 1. However, this is thus not always the case as explained below.

The wage costs are made discrete by assuming a fixed amount of FTEs deployed, which is more realistic. This results in a positive scale effect on the per unit charging cost by increasing the fleet size up until the point that an extra FTE should be hired, where the curve jumps up again. For options 1 and 3, these jumps appear at different fleet sizes, causing this effect as shown in Figure 3.14. If the wage costs would be calculated continuously based on the amount of hours needed to perform the charging, then the charging costs for options 1 and 3 would be like in Figure 3.15. In this case, it can be clearly seen that option 2 is cheaper than option 1 and that option 3 is the average of the two since the split is set at 50% here.

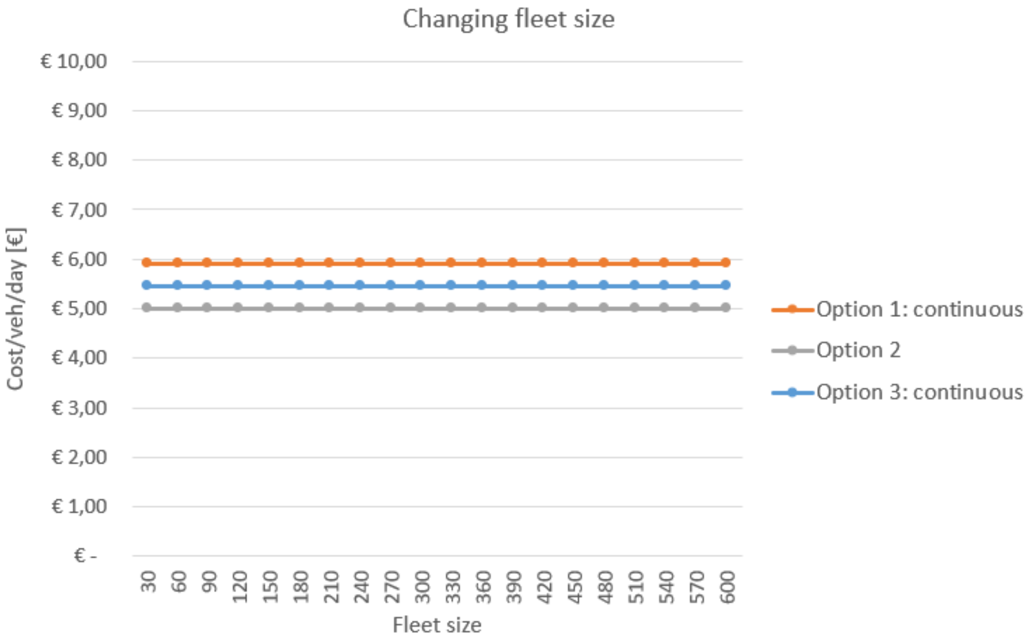
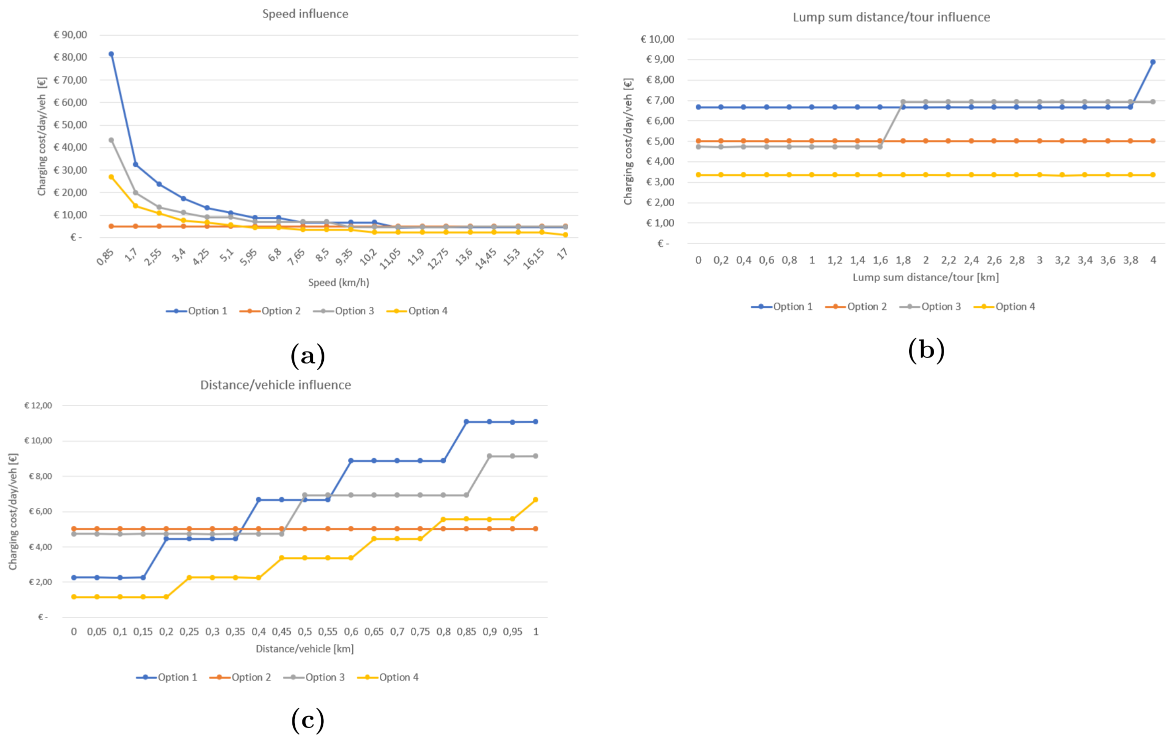


Figure 3.15: Charging costs option 1 and 3 with continuous wage costs

Finally, sensitivity analysis was performed on the most critical parameters in the charging model, being the relocation speed, the lump sum distance per milk run and the intra-scooter distance. It can be observed from Figure 3.16 that the influence of the speed is on a steady state from 8.5km/h, which is taken as the conservative estimate in the model. The lump sum distance per tour only has an influence in Option 3, but the most significant factor is the intra-scooter distance as seen in Figure 3.16c. The base value of 0,5km is a conservative estimation, which should allow for safe, but realistic modelling.



(a) **(b)** **(c)**

Figure 3.16: Sensitivity analysis on charging model parameters

3.3 Revenue models for micro-mobility providers

The final component of the financial model is the revenue generation. The ITDP [60] mentions that most publicly funded systems require a combination of sponsorship, membership fees and tax revenues to cover the operating costs. Privately operating systems should cover their costs by funding from venture capital, advertising, trip fares and user deposits. For the latter, the long-term profitability is yet to be proven, which is the subject of this project.

Revenue generation through ridership will be considered in this project from two point of views. First of all, the total discounted cost of the system, together with a fixed demand input, can be translated into a price setting. Existing pricing schemes can be used to benchmark these price settings to derive meaningful conclusions. This reasoning can be turned around by deriving the minimum demand needed to cover the total cost of the system with the existing pricing schemes.

3.3.1 Pricing schemes: bike sharing providers

Pricing schemes of bike sharing providers are typically on pay-as-you-go basis or as a membership fee. Examples are listed below from currently active free-floating or hub-centric bike sharing providers in Belgium.

DonkeyRepublic is a hub-centric bike sharing provider active in Ghent, Belgium. It allows its users to rent a bike on pay-as-you-go or by a membership, see Table 3.15

Price [€]	**Time**
1,7	< 15min
2,2	< 30min
3,3	< 1u
5	< 2u
7,5	< 4u
9	< 6u
11	< 12u
13	< 1 day
22	< 2 days

Price [€]	**Time**	**Description**
14	month	Unlimited rides 1h free per ride All pedal bikes In all cities
19	month	Unlimited rides 12h free per ride All pedal bikes In all cities

Table 3.15: DonkeyRepublic pricing schemes

A second free-floating bike sharing provider active in Belgium is *Mobit*. They are currently operational in Courtrai, Aalst, Mechelen, Antwerp, Genk and Hasselt. There pricing scheme is pay-as-you-go per block of 20 minutes, shown in Table 3.16. They are clearly cheaper per minute than DonkeyRepublic.

Price/20min [€]	**Time**
0,45	< 1u
0,65	< 2u
0,80	< 3u
1	> 3u

Table 3.16: Pay-as-you-go pricing scheme Mobit

Thirdly, there is a free-floating bike sharing company active in Antwerp, *Cloudbike*, deploying 360 bikes over the city. They have both a membership option as the pay-as-you-go option available. Prices are given in Table 3.17

Price [€]	Time
0,05	min
13	day

Price [€]	Time	Description
20	3 months	Max 40min per ride
40	6 months	Idem
72	12 months	Idem

Table 3.17: *Cloudbike* pricing schemes

3.3.2 Pricing schemes: e-scooter providers

All e-scooter systems deployed in Belgium (and worldwide) work with a similar pricing scheme. They charge a fixed fee per ride and a variable fee per minute. *Dott* is the largest active player in Brussels with around 1.600 steps. In Antwerp, there are *Poppy*, *Circ* and *Bird*, each deploying between 100 and 200 e-scooters. The prices vary over time and are given in Table 3.18.

Price [€]	Time	Description
1	Per trip	Fixed fee to unlock
0,2-0,3	min	Tarif per minute

Table 3.18: E-scooter tarifs

3.4 Cost models

Now that all cost modelling building blocks have been discussed, they can be translated into a generic cost model for both use cases. These cost models will serve as basic tool for performing cost analysis to derive scalability insights and possible viability conditions. By setting the different input parameters as realistic as possible, different real-life scenarios can be studied.

3.4.1 Hub-centric bike sharing cost model

The unit costs together with the other modelling assumptions discussed in the previous sections can be converted to a financial cost model. In this model, all costs will occur as cash flows being either one-off or recurring. The identification is already shown in Figure 3.8. Table 3.19 gives an overview of all upfront costs made by a bike-sharing provider.

Variable costs are kept generic by expressing them as a cost per unit. Table 3.20 shows all recurring costs with an indication of the time frequency by which they occur. Recurring costs repeat themselves in the cash flow by their time frequency during the total time horizon of 5 years.

Category		**Amount [€]**	**Unit**
IT&Marketing	Website	5.000	
Administration	Start-up	1.500	
Platform	Development	116.800	
	Testing	40.880	
	Subtotal	**157.680**	
Assets	Bikes	100	/bike
	Locks	50	/bike
	Batteries	2	/bike
	GPS tracker	15	/bike
	SIM-card	2,5	/bike
	Subtotal	**169,5**	**/bike**
	Gear	10.000	

Table 3.19: One-off costs: bike sharing case

Extra calculations are used in the recurring costs of the bike-related assets that need some explanation. These costs incur because the assets have a limited life time due to durability, theft or damaging. It is assumed that the vehicles reach the end of their life expectancy uniformly over a year. The recurring assets costs per month are then calculated using the following formula:

$$\text{Recurring assets cost/month} = \frac{\text{Initial cost}}{\text{life expectancy (years)} * 12}$$

Category		Amount [€]	Unit	Period
Assets	Bikes	4,17	/bike	month
	Locks	1,04	/bike	month
	Batteries	0,08	/bike	month
	GPS tracker	0,31	/bike	month
	SIM subscription	1,75	/bike	month
	Subtotal	**7,35**	**/bike**	month
	Warehouse rent	3,75	/m²	month
	Van lease	455	/van	month
IT&Marketing	Web hosting	16,67		month
	Social media	200		month
	Subtotal	**216,67**		month
Administration	Company contr.	350		year
	Insurance	28	/bike	year
Platform	Maintenance	8.500	/FTE	month
Operations	Relocation	*Case dependent*		month
	Customer supp.	6.800	/FTE	month
	Maint. Staff	6.800	/FTE	month
	Repair costs (material)	2,5	/bike	month
MM&Overhead	Manager wage	10.200	/FTE	month
	Marketeer wage	6.800	/FTE	month
	Utilities	0,3	/m²	month

Table 3.20: Recurring costs: bike sharing case

3.4.2 Free-floating e-scooter cost model

A cash flow table with the capital expenses and recurring costs is constructed in the same way as explained for the bike sharing providers. The one-off costs are shown in Table 3.21 and the recurring costs per time period are shown in Table 3.22. The values shown are for operating options 1, 2 and 3, but are similar for option 4. Only the e-scooter and battery costs differ. Recurring asset costs are calculated using the same formula as in the other case.

Category		**Amount [€]**	**Unit**
IT&Marketing	Website	5.000	
Administration	Start-up	1.500	
Platform	Development	145.500	
	Testing	50.925	
	Subtotal	**196.425**	
Assets	E-scooters	500	/scooter
	Chargers	18	/charger
	Batteries	95	/battery
	SIM-card	2,5	/scooter
	Gear	10.000	

Table 3.21: One-off costs: e-scooter sharing case

Category		**Amount [€]**	**Unit**	**Period**
Assets	E-scooters	250	/scooter	month
	Chargers	0,75	/charger	month
	Batteries	-		
	Warehouse rent	7	/m²	month
	Van lease	455	/van	month
IT&Marketing	Web hosting	16,67		month
	Social media	200		month
	Subtotal	**216,67**		month
Administration	Company contr.	350		year
	Insurance	50	/scooter	year
Platform	Maintenance	8.500	/FTE	month
Operations	Charging	Case dependent		month
	Customer supp.	6.800	/FTE	month
	Maint. Staff	6.800	/FTE	month
	Repair costs (material)	23	/scooter	month
	Payment proc.	0,05	/trip	month
MM&Overhead	Manager wage	10.200	/FTE	month
	Marketeer wage	8.500	/FTE	month
	Utilities	0,3	/m²	month

Table 3.22: Recurring costs: e-scooter sharing case

Chapter 4

Case 1: Hub-Centric bike-sharing system

This chapter will go into depth of the results of the cost model for hub-centric bike sharing providers. The cost model is built as explained in Chapter 3 first to obtain the total NPV and AW of the costs. By performing sensitivity analysis on the different cost categories, the most important levers in the system will be made clear. They can indicate search spaces to look for improvement. The next step is to construct specific and well-chosen scenarios by varying the levers obtained from the sensitivity analysis. The impact on the cost structure will be evaluated in detail. After that, the modelling assumptions can be set realistically to represent Belgian cities where hub-centric bike sharing systems are active. Their pricing schemes can be benchmarked for viability by applying the average demand input to the cost structure, as explained in the previous chapter.

4.1 Cost model

The results of the cost model are dependent on the modelling assumptions. A realistic base case scenario should be set. It is chosen to take the existing data from *Cloudbike* as input [66]. A total fleet size of around 350 free-floating bikes is active in an operational area in Antwerp with a size of 18km^2. Similar programs with a same fleet size and area exist in other cities such as Mechelen, Courtrai and Ghent. The modelling assumptions are shown in Table 4.1.

Model assumptions	**Amount**	**Unit**
Time horizon	5	years
Discount rate	15	%
Inflation rate	2	%
Amount of cities	1	
Fleet size	350	bikes
Distance from depot	20	km
Warehouse size	0,5	m^2/bike
Area size	18	km^2

Table 4.1: Case 1: modelling assumptions

Applying the cost structure framework with the one-off and recurring costs as explained in Chapter 3 together with these modelling assumptions, results in the cost model shown in Tables 4.2 and 4.3. These tables serve as input to generate a cash flow table of the costs, from which the NPV of the cost over five years can be calculated. This NPV is then translated into an annual worth.

Category		**# units**	**Amount [€]**
IT&Marketing	Website		5.000
Administration	Start-up		1.500
Platform	Development		116.800
	Testing		40.880
	Subtotal		**157.680**
Assets	Bikes	350	35.000
	Locks	350	17.500
	Batteries	350	700
	GPS tracker	350	5.250
	SIM-card	350	875
	Subtotal		**59.325**
	Gear		10.000
		TOTAL:	**€ 233.452**

Table 4.2: Case 1: one-off costs

Category		**# units**	**period**	**Amount [€]**
Assets	Bikes	15	month	1.458,33
	Locks	7	month	364,58
	Batteries	15	month	29,17
	GPS tracker	7	month	109,38
	SIM subscription	350	month	612,50
	Subtotal		**month**	**2.573,96**
	Warehouse rent	175	month	656,25
	Van lease	2	month	910
	Subtotal		**month**	**1566,25**
IT&Marketing	Web hosting		month	16,67
	Social media		month	200
	Subtotal		**month**	**216,67**
Platform	Maintenance	1	month	8.500
Operations	Relocation	2	month	8.050,17
	Cust. support	1	month	6.800
	Maint. staff	1	month	6.800
	Repair costs (material)	350	month	875
	Subtotal		**month**	**22.525,17**
Administration	Company contribution		year	350
	Insurance	350	year	9.800
	Subtotal		**year**	**10.147,5**
MM&Overhead	Manager	1	month	10.200
	Marketeer	1	month	6.800
	Subtotal		**month**	**17.000**
	Utilities	175	month	52,5

Table 4.3: Case 1: recurring costs

The total NPV of the costs is translated to an annual equivalent worth (AW). The values are given in Table 4.4. The total NPV of the costs can be broken down into its cost categories to discover the overall most important costs. This is shown in the pie diagram of Figure 4.1. It is clear that the operational costs are the most significant with an overall percentage of 38% of the total cost of the system. This was expected due to the labour intensive operations such as relocation and bike repair. The second largest category with 29% is management and overhead costs, however these costs cannot be reduced, since they are largely induced by staffing costs. On the third and fourth place, a significant amount of cash is spent to platform maintenance and initial investment (15% and 9%). In this base case, the development and maintenance of the platform is done in-house and is the main driver of these high costs.

Results	**Amount**
PV costs (5Y)	€ 2.686.145
AW costs	€ 801.319

Table 4.4: Case 1: results of discounted costs

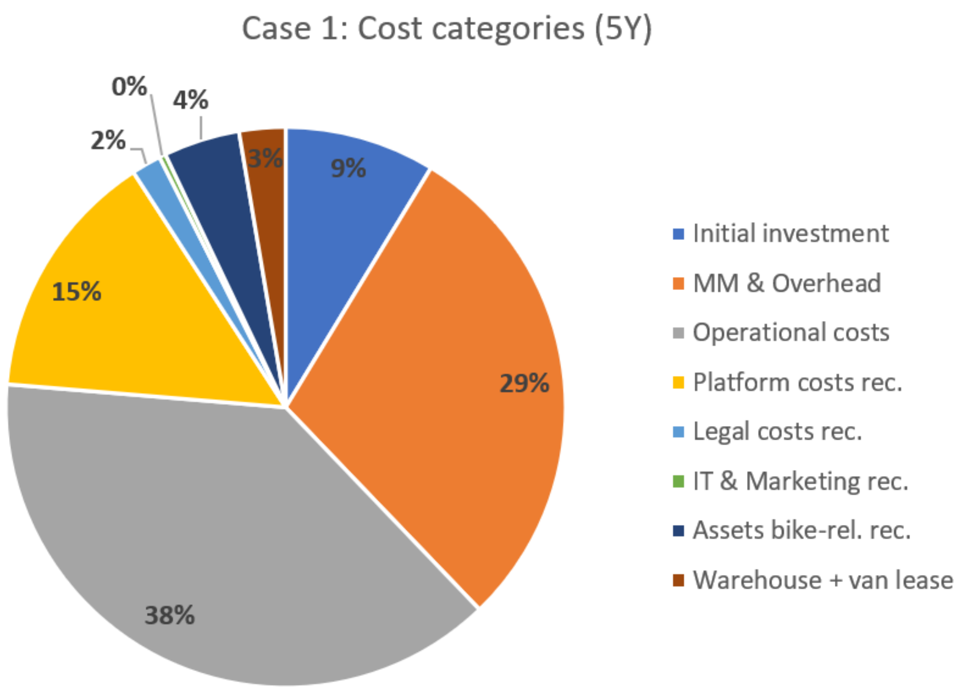


Figure 4.1: Case 1: cost categories based on NPV

Because the operations seem to be the largest cost category, a closer look is taken on them in Figure 4.2. Relocation proportion (36%) comes out most important in this scenario, as expected. It is mainly driven by the amount of FTEs to perform the relocation, which is calculated as two in the base case, and the amount of days relocation is performed. According to a recent source, this number was set at 3 times a week [67]. Maintenance staff is the second highest cost driver in the base case, but it is very case dependent due to the way it is modelled. At least one FTE is implemented per 300 vehicles, causing discrete cost rises depending on the fleet size.

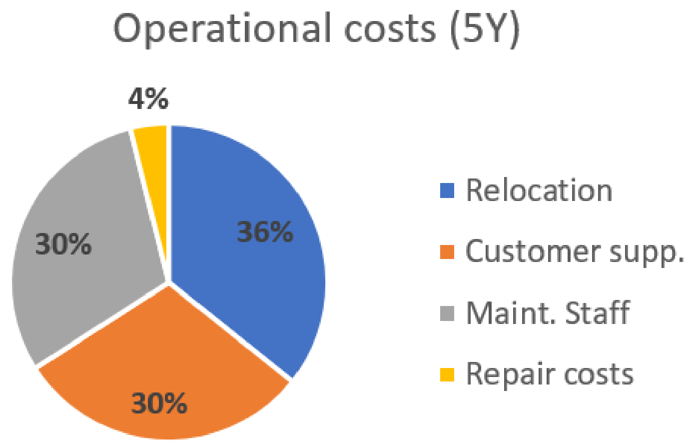


Figure 4.2: Case 1: operational cost categories based on NPV

4.2 Demand input

Different viability conditions will be derived based solely on the cost structure primarily. However, by considering an average and realistic demand input for certain cities, break-even pricing can be derived from the cost model. This price setting can then be benchmarked against current pricing schemes of existing companies as displayed in Chapter 3. This reasoning can also be done vice-versa by deriving the minimum demand needed with a given pricing scheme to break even. For both options, the average demand is needed to make the evaluation.

For Belgian cities, such as Ghent, Courtrai, Antwerp or Mechelen, utilization ratios are reported as fairly low. In the regulations of Antwerp, a minimum utilization of the entire fleet of 0,5 rides/bike/day is required after the second year of operation [68]. *Mobit* had a record month in January 2020 with 1 ride/bike/day in Mechelen according to [67], while their 2019 average in Courtrai was around 0,5 rides/bike/day [69]. Finally, the utilization of *Cloudbike* bikes in Antwerp was reported to be around 0,4 rides/bike/day in 2018 [66].

When considering optimistic scenarios, the Antwerp regulations give the permission to enlarge the fleet size if the criteria of 3 rides/bike/day is reached [68]. This scenario is realistic when considering larger, touristic cities such as the numbers for Barcelona (6.4), Paris (4.5) or NYC (6.4) from 2017 report [60].

The average demand inputs shown in Table 4.5 will be used in the remainder of the analysis. The base case scenario will use the current average demand of 0,5 rides/bike/day for Belgian cities.

Scenario	Demand [rides/bike/day]
Base case	0,5
Max	1
Target	3
Touristic	5

Table 4.5: Case 1: demand input scenarios

4.3 Standard sensitivity analysis

To further evaluate the importance of the different cost drivers or levers in the model, a standard sensitivity analysis is performed. The values of each main cost group were varied from -100% to +100% compared to the base case. The influence on the NPV for each category is displayed in the spider-plot in Figure 4.3.

Management and overhead is again indicated as the primal cost driver, which can be seen by the steeper curve meaning that the cost is more influential. It is followed by the maintenance staff that is needed to keep the fleet operational. More important to notice is the high impact of platform maintenance. This factor occurs because it is considered as an in-house cost in the base case. Together with the platform development, which is shown by the red curve, they result in a large cost to the system. It can be further evaluated whether there are other options, for example to outsource these costs to a third party.

The relocation costs are the third most important cost in this cost model. As explained earlier in Chapter 3, bottom-line this cost is induced by the amount of FTEs and the amount of days relocation will be performed. The output of the base case scenario, resulting in two FTEs to perform this job seems realistic. Relocation operations should in the ideal scenario result in a higher utilization of the bikes. Results in the remainder of this analysis will be under the assumption of the applied relocation strategy.

The recurring costs for bike-related assets is the last factor that seems to have a noticeable impact on the total discounted cost of the system. The main driver for this cost is the life expectancy of the bikes. It can be evaluated to what extend it should be lengthened in order to have a significant impact on the total cost.

Other factors such as repair costs, customer support or warehouse rent and van lease, do not impact the NPV greatly. It can be concluded that their estimations can be considered as safe in this model.

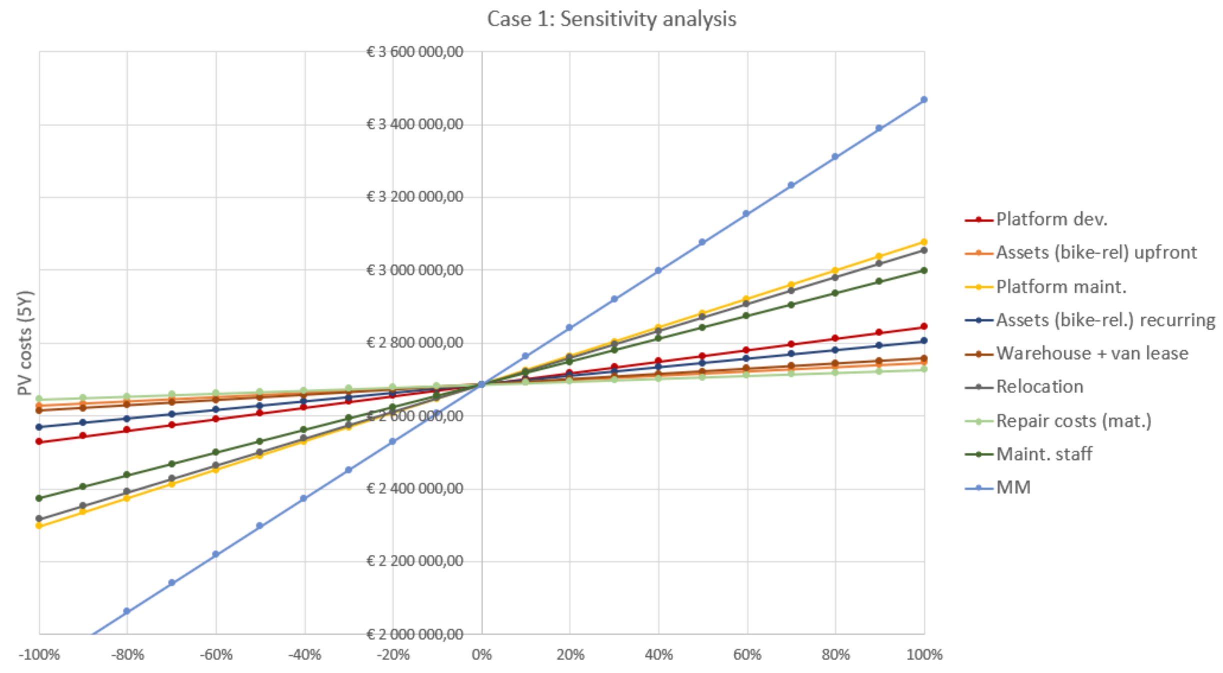


Figure 4.3: Case 1: sensitivity analysis of cost categories on NPV

4.4 Scenario analysis: impact of generic levers

The next step in deriving viability conditions is to set up well-chosen scenarios. The impact of changing important levers on the cost will be evaluated primarily. Once the impact is known, real-life use cases will be constructed to evaluate the existing pricing schemes. Different scenarios will permit to derive the needed combination of parameters to result in a sustainable and profitable business.

4.4.1 Life expectancy

Considering the hardware in the system, the life expectancy of all bike-related costs, such as the bikes themselves, the GPS trackers and the Bluetooth locks, is the most important cost driver. It is important for a company to know whether they should invest or look out to further reduce the cost of their assets. This is even more important when they are the means to generate revenue. The impact of the life expectancy of the bikes on the AW of the costs is shown in Figure 4.4.

In the base case scenario, the life expectancy is 2 years. This is a realistic assumption and calculated to be 2.7% less expensive over only 1 year life expectancy. Improving the life expectancy even further to 4 years, will reduce the annual costs with only 1.25% as shown in Table 4.6. If prices are adapted to these costs, a 1.25% cheaper price can be offered to the customers. Because of the low gains, this will not be a determining factor for viability of these providers.

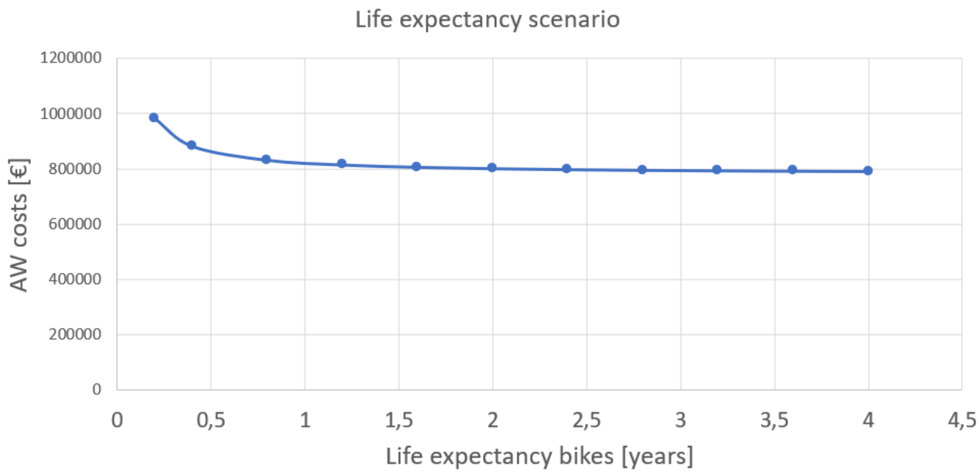


Figure 4.4: Case 1: impact of bikes' life expectancy

Life expectancy	AW costs [€]	Abs. diff.* [€]	Rel. diff.*
1 year	822.950	+21.631	+2.7%
2 years	801.319		
4 years	791.335	-9.984	-1.25%

*Difference from the base case scenario of 2 years

Table 4.6: Life expectancy of bikes

4.4.2 Scalability

In the base case scenario, a fixed fleet size of 350 bikes is assumed. An important measure for these types of businesses is the effect of scalability. Is it worth to produce, in this case to roll-out, more vehicles to lower the cost per vehicle? By scaling up, the fixed costs can be spread over more units, while more units also induce more variable costs. How does this weigh up in this case and is there a positive scale effect? Two scenarios can be made to answer this question. First, the scalability within one city will be evaluated. Secondly, the scale effect of operating the platform over multiple cities is considered. The difference between the two scenarios is the need of duplication of several costs, such as the amount of warehouses or amount of employees to manage the system. The differences are discussed in the next sections.

4.4.2.1 Scalability within one city

Varying the fleet size within one city will result in higher overall costs of the system due to all variable costs related to the amount of vehicles. Some costs that are not dependent on the amount of vehicles are the wage costs for the manager and marketeer, the upfront development cost of the platform and relocation costs. By enlarging the fleet size, these costs can be spread amongst more vehicles. In Figure 4.5 it can be seen that there clearly is a positive scale effect. The blue curve shows the AW of the costs that rises as a stairs function of the fleet size. This is because the amount of FTEs to perform the maintenance is modelled discretely as one FTE per 300 bikes as a rule of thumb.

Figure 4.5: Case 1: positive scale effect within one city

Fleet size	Cost/bike/day [€]	Reduction*
210	10	
300	7,2	-28%
350	6,27	-13%
490	5,2	-17%
595	4,4	-15%
665	4,01	-9%
805	3,75	-7%
875	3,5	-7%

*Cost reduction compared to previous fleet size

Table 4.7: Case 1: scale effect

In Table 4.7, some values close to these critical points are shown. It can be seen that after the "jumping points" of multiples of 300, the cost reduction is smaller. However, overall the cost/bike/day keeps dropping noticeably by increasing the fleet size. The effect of thorough planning and fleet size optimization can be an important business insight for these providers.

The marginal cost per day for adding one additional bike is found to be only €0,69 on all levels, except on critical points where extra maintenance staff needs to hired. The extra cost per day for adding one extra bike on these points is €256 under these discrete modelling assumptions. This is shown in Figure 4.6. Translating this to a demand level given a price of about €2/trip, each additional bike should be able to generate at least 0,345 rides per day and at the critical points 128 rides per day.

For the scenario shown in Figure 4.6, a fixed market with an absolute demand of 3 rides/bike/day for an operator deploying 500 bikes could be assumed. This means a total market size of 1.500 rides per day. The effect on break-even pricing when varying the fleet size for this fixed absolute demand is plotted in Figure 4.6 as well. It can be observed that pricing is very robust, as it only increases 1 cent per 20 extra bikes in the system.

These are useful indications for planners to be aware of the low extra demand needed per extra vehicle to deploy, dependent on how large the fleet size is at the time of making decisions on expanding. If no extra employees should be hired by adding a bike, it should only be able to generate a low amount of demand to be worth it or equivalently the effect on break-even pricing is negligible.

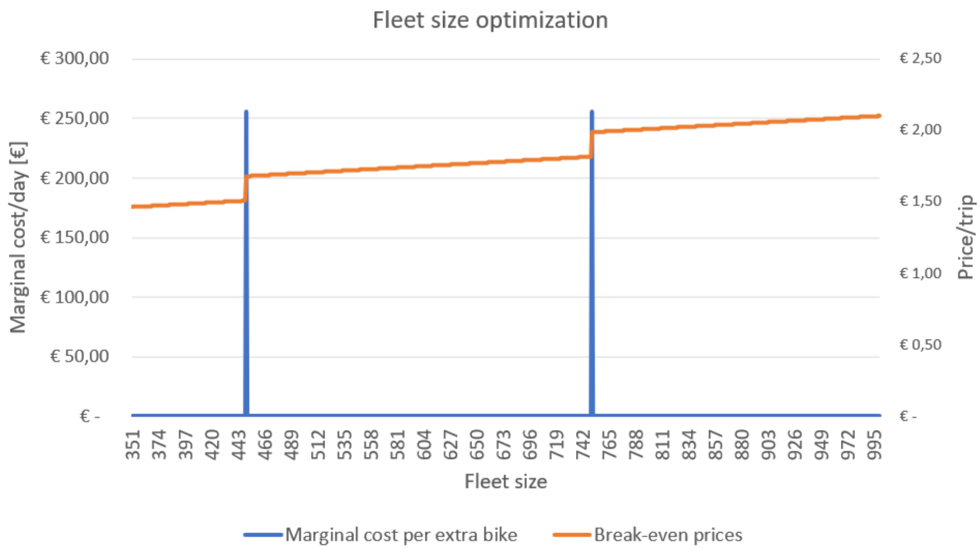


Figure 4.6: Case 1: marginal cost curve

4.4.2.2 Scalability over multiple cities

In Belgium, there are several companies that are already active in multiple cities. *Mobit* is active in for example Antwerp, Hasselt, Mechelen and Aalst, while *DonkeyRepublic* will soon be operational in Ghent and Courtrai. Expanding over multiple cities could also result in a positive scale effect.

To examine the effect of being active in multiple cities, the modelling assumptions are kept the same in each city. This means equal fleet sizes and operational area sizes in all cities. Besides the variable costs per vehicle, such as the purchase cost of the bikes, there are other costs that need duplication independent of the amount of vehicles. They are listed below:

- **Van lease**: Vans are needed in each city to perform the operations.
- **Gear**: Warehouse gear and tools.
- **Warehouse**: Considering that the cities are not adjacent to each other, an extra central warehouse per city is needed as base center.
- **Relocation**: Relocation costs are dependent of the area size per city and is desired in every city.

- **Manager**: *DonkeyRepublic* [70] advises to hire at least one FTE to manage the operations per city.
- **Customer support**: There should be some customer support available the entire week in each city [68].
- **Marketeer**: It is debatable whether multiple marketeers are needed. It depends on the tasks and workload they already perform within a city. In this scenario, this cost will be duplicated, as the role of the marketeer can be interpreted as a versatile employee.

In a first scenario, as explained, the modelling assumptions are kept the same and every extra considered city has 350 bikes over an area of $18km^2$ as well. It must be noted that the duplication of manager, marketeer and customer support to each city is the worst case scenario. Possibly, multiple cities could be served by one customer support service, however this cannot be estimated. Under these assumptions, there is a positive scale effect to be seen in Figure 4.7a showing the cost/bike/day. The cost per bike per day drops by as much as 15% in this worst case scenario.

However, the scale effect is dependent on many other factors in this case. If the amount of bikes in the first city is set higher (e.g. 600) than in the extra cities in which the program will be enrolled, a negative scale effect can be seen in Figure 4.7b. When looking at the unit economics per city, it is obvious that the cost per bike in the first city, with larger scale, will be lower. By expanding the operations, the spreading of the fixed costs over multiple cities does not add up with the worse unit economics of the extra cities. This makes sense since the fixed costs are much lower than the variable costs. So the average cost will become higher by being operational in additional cities.

(a) Every city 350 bikes **(b)** First city 600 bikes, other 350

Figure 4.7: Scale effect over multiple cities

Having a smaller fleet size in additional cities is not the only factor that can lead the expansion over multiple cities to result in a negative scale effect. The relocation costs are dependent on the area size. Additional cities that are larger require higher relocation costs, that can again diminish the positive scale effect.

The conclusions that can be drawn from this scenario are dependent on specific conditions. The scale effect over multiple cities will be very case-specific and dependent on multiple considerations. Expanding operations to multiple cities may have a positive scale effect under the conditions that additional cities operate at least as many vehicles generating the same average demand. A negative scale effect does not mean directly for a business that expanding is not worth it. If margins can be kept at a satisfying level, then profit can be increased by expanding nonetheless. The positive scale effect within one city is a clear observed effect and will be evaluated further by coupling it to a demand input.

4.4.3 Platform costs: in-house vs third party

The platform costs in the base case consist of two parts. The first cost is the development of the platform, which is an upfront cost. For many small initiatives, the initial investments can be a too large burden to overcome. Besides the initial investment in developing a platform, there are always recurring costs for the maintenance. Considering the large upfront investment and the fact that there are already significant recurring costs, one could consider outsourcing the software. *DonkeyRepublic* is a bike sharing operator active worldwide, giving the option to private owners of a fleet to use their platform and all other facilitating services. The payment for the system they propose, is a revenue split of 80% that is kept and 20% to be paid to *DonkeyRepublic* [70].

This option is evaluated compared to the base case in-house platform development and maintenance. This is done by omitting these two costs in the NPV calculation and than dividing the obtained total discounted cost by 0,8. The reason for calculating it this way is because the prices (and thus the revenue per month) are unknown in this stage having only the cost model. The results are given in Table 4.8. It can be observed that the total cost of the system gets slightly less expensive when outsourcing. It must be noted that the estimation of the development and maintenance cost when made lower, could result in the opposite effect. Prices are derived from these costs to show the impact of this difference. Over the period of five years, this would only result in a 1 cent difference in break-even pricing.

PV costs	€ 2.686.145	**PV costs**	€ 2.672.917
AW costs	€ 801.319	**AW costs**	€ 797.372
Demand input	3 rides/bike/day	**Demand input**	3 rides/bike/day
Price	€ 2,09	**Price**	€ 2,08

Table 4.8: Case 1: in-house vs outsource software

It is interesting to observe that at the level of 20% revenue split, operators should be indifferent between choosing for in-house or outsourced software. From a business perspective it can be evaluated up to which point this is the case. The evolution of the break-even prices for varying revenue cost proportion when outsourcing software is shown in Figure 4.8. If the amount of the revenue that has to be paid to the provider of the software can be negotiated below 21%, the operators will benefit over the five year planning horizon.

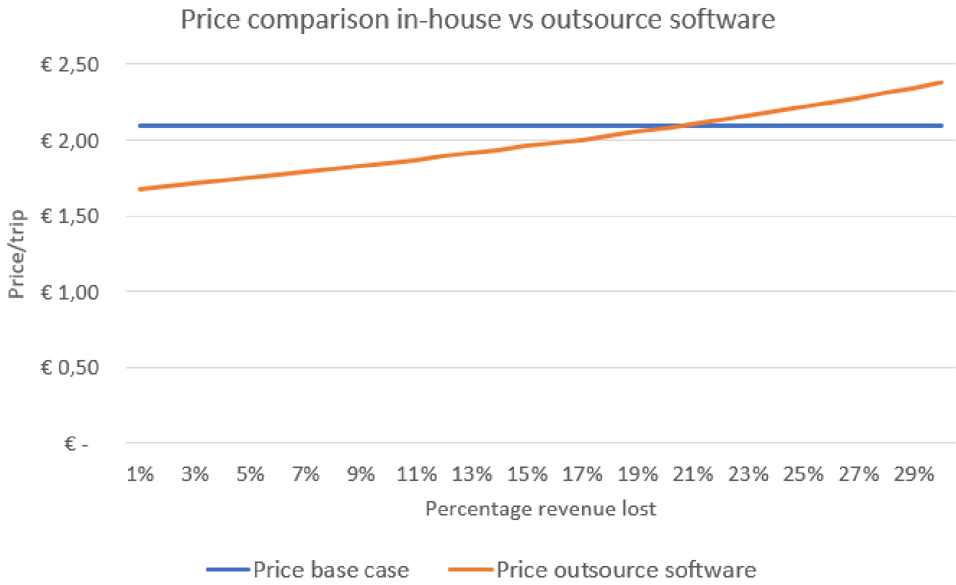


Figure 4.8: Case 1: variation of revenue split for outsourcing software

The impact of choosing to outsource software costs, lies in the upfront savings that give the operators an advantage over time, because they are piling up costs in the first few months/years over which normally less revenue is generated than these costs. In this specific case, they can already safe around €160.000. This gives them an advantage that could over time result in a reduction of the maximum cumulative discounted costs, which is often called the "valley of death". This point indicates how much money is needed to survive the investment. In this project, it was unfortunately impossible to calculate the valley of death point, because no adoption curve is implemented. The reason for this is because it is not the aim of this study to forecast the future potential of a new and non-existent business, but to evaluate current systems as they are performing at the time being. However, no open source data can be found on market penetration in the last few years. Only the average usage per bike is known and therefore implemented dynamically as an average of this five year time period.

4.5 Use cases: pricing and demand comparison

All important and impactful levers of the system have been discussed now. The final part of the analysis consists of evaluating existing systems in real-life scenarios and modelling circumstances. The viability of the existing systems will be primarily derived from the pricing schemes and demand input. In the case that the primal results indicate that a system is not viable, potential impactful costs will be brought to light and parameters and conditions will be derived under which the business can be sustainable. The focus will be on evaluating these systems in Belgian cities primarily. They can then be compared to larger or more attractive cities to show the difference.

4.5.1 Current small scale systems

In Section 4.2, there are three active free-floating non-electric bike sharing systems mentioned. Currently these systems operate at a small case compared to existing station-based systems. The first scenario in the base case considers only one city, deploying 350 bikes. This is more or less the average of these systems in this phase of their roll-out in Belgium. It must be noted that no adoption curve will be considered over the time horizon, because it is the aim to derive long-term viability conditions. This implicates the assumption of a mature and stable market.

Active in one city

The modelling assumptions for a player active in Antwerp are shown in Table 4.9. These circumstances are similar for Ghent or Courtrai.

Input parameter	Amount	Unit
Area size	20	km^2
Amount of bikes	350	bikes
Current demand	0,5	rides/bike/day
Max demand	1	rides/bike/day
Target demand	3	rides/bike/day
# relocation days	3	days/week

Table 4.9: Case 1: small scale scenario modelling inputs

The evaluation of the current performance, with an average demand of 0,5 rides per bike per day, will be done first by benchmarking the obtained price per trip to current pricing schemes. The price setting is highly dependent on the demand input. For this reason, the maximum observed average monthly demand in free-floating systems in Belgium of 1 and the target demand of 3 rides/bike/day is also considered. The obtained break-even prices compared to the existing pricing schemes are given in Table 4.10. The price evolution with growing demand is shown in Figure 4.9.

The price per trip to break even is highly dependent on the demand input. At the current demand level, the maximum existing pricing scheme of € 1.7 per trip is far too low compared to the output of the model suggesting a price of € 12,55 per trip. Even when the capital upfront expenses are left out of consideration, the system is not viable at current prices. The reason for setting prices this low could be to attract customers in the early phase of the adoption or that customers are not willing to pay more. When targeting an average demand of 3 rides per bike per day, as suggested by literature, the operational pricing of € 1,91 comes closer to the existing price of € 1,7.

	Break-even pricing [€]	Operational pricing[€]
NPV costs	2.686.145	2.452.692
AW costs	801.319	731.676
Price (d=0,5)	12,55	11,45
Price (d=1)	6,27	5,73
Price (d=3)	2,09	1,91

d = Average demand = rides/bike/day

Operator	Price/ride [€]
Mobit	0,45
Cloudbike	0,75
DonkeyRepublic	1,7-2,2

Table 4.10: Case 1: small scale scenario price setting vs existing schemes

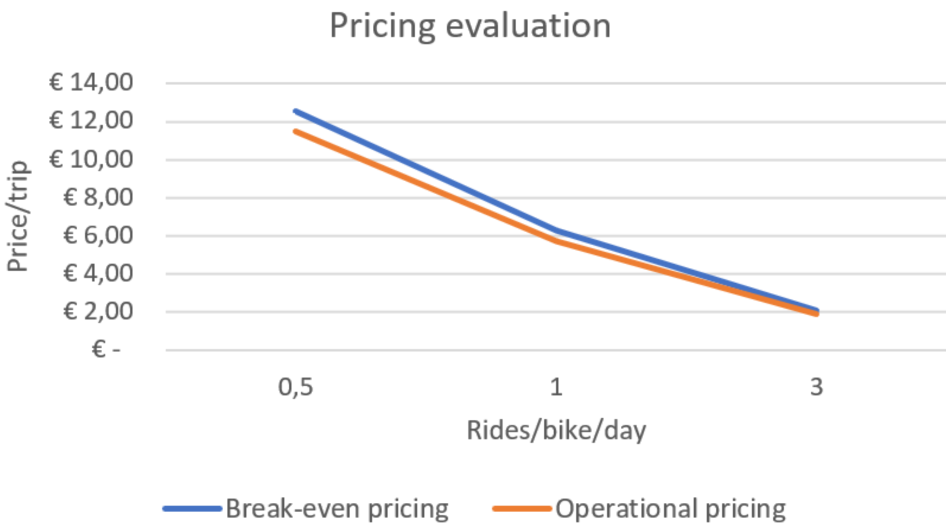


Figure 4.9: Case 1: price setting small scale scenario

Scale over multiple cities

A second scenario that should be considered to evaluate current systems on viability is operators being active in multiple cities. This is also the case or the aim for most providers. *DonkeyRepublic* is currently active in Ghent with around 300 bikes and will expand its activities to Courtrai with 300 bikes as well. *Mobit* is active in Courtrai, Hasselt, Mechelen, Aalst and Antwerp. The latter case can be modelled by using the input parameters shown in Table 4.11.

The results in Table 4.12 again indicate that the system is not viable under current pricing schemes and only indicate a minor positive scale effect compared to only being active in one city. A minimum of 3 rides per bike per day is needed in the long term to be viable with current pricing. The expansion over multiple cities, as modelled in this project under the assumptions mentioned, will not be the solution to tackle the problem in the short term.

City	**Amount (bikes)**	**Size [km²]**
Antwerp	300	70
Courtrai	250	24
Mechelen	300	22
Hasselt	350	40
Aalst	150	4

Table 4.11: Multiple cities parameters

	Break-even pricing [€]	**Operational pricing[€]**
NPV costs	9.890.402	9.447.450
AW costs	2.950.461	2.818.321
Price (d=0,5)	11,98	11,44
Price (d=1)	5,99	5,72
Price (d=3)	2,00	1,91

d = Average demand = rides/bike/day

Table 4.12: Case 1: scaling over multiple cities

4.5.2 Best case scaling up scenario

What possibly limits the factor of scaling up at the moment is the presence of large station-based systems in cities like Antwerp and Brussels [71], [72]. In those cities, there are respectively 4.000 and 5.000 active SB bicycles, good for an average of 4,5 and 1 rides/bike/day. In the best case scenario, those systems could be replaced by the newer free-floating systems. If regulators would organize this system in a way that maintains public order and keeping it user-friendly, the assumption can be made that this higher demand per bike can be reached as well.

In this scenario, four demand inputs are considered. The current average demand of 0,5 rides/bike/day, increasing to 1 as observed in the SB system in Brussels, the target demand of 3 and the most optimistic demand of 4,5 as the average of *Vélo* in Antwerp. This will be done by gradually increasing the fleet size to evaluate the scale effect on the price setting. This will permit to evaluate the importance of scaling up within one city and the effect on the needed demand to cover costs at current pricing.

The scale effect for these four different demand inputs is shown in Figure 4.10. From the trend of these curves it can be observed that there is a noticeable scale effect up until around 2.000 bikes. Prices at given fleet sizes are given in Table 4.13. For the current demand input of 0,5, current pricing schemes can never be competitive even if they scale up to 2.500 bikes. When increasing fleet size to a maximum of 2.500 in the case of 1 ride/day/bike, pricing would be € 2,49 which comes close to the price of *DonkeyRepublic* for a half an hour drive (€ 2,2). The most important general take-away is that there is a clear positive scale effect when increasing fleet size within one city.

In the long term, providers should target to an average demand level which is dependent on their fleet sizes. Having a relative small fleet size of 500 bikes, the target should be a demand of at least 2,5 rides/bike/day with current pricing schemes. Making this nuance, depending of the fleet size rolled out, an average demand between 1,2 and 2,6 rides/bike/day makes the system viable. At the average expected target of 3 rides per bike per day, a fleet size as small as 350 bikes is viable with current pricing schemes.

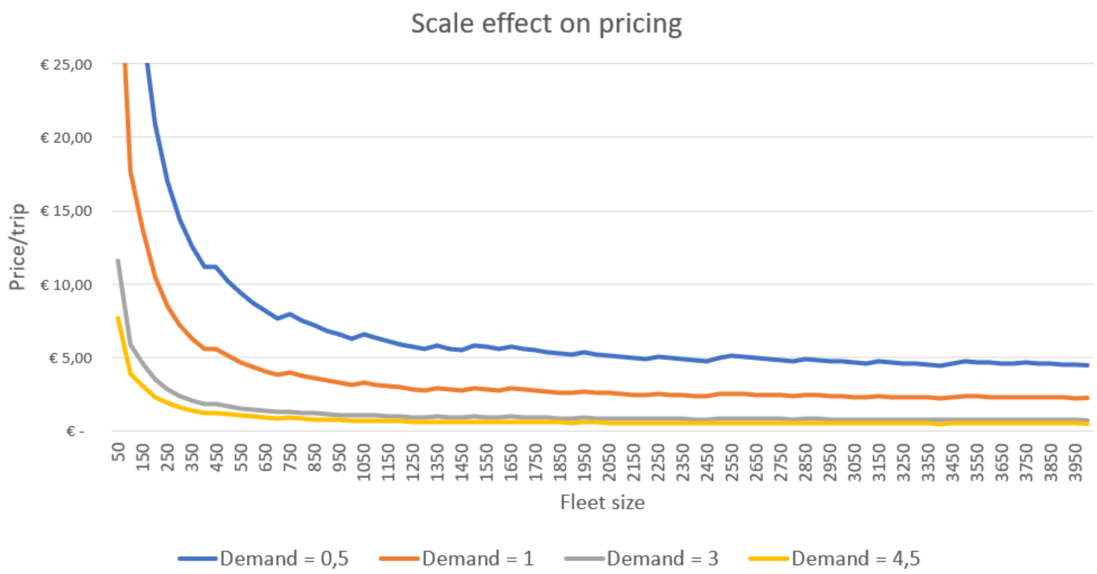


Figure 4.10: Case 1: large scale scenario

Fleet size	Price (0,5) [€]	Price (1) [€]	Price (3) [€]	Price (4,5) [€]
250	17,01	8,51	2,84	1,89
500	10,21	5,11	1,7	1,13
750	7,95	3,97	1,32	0,88
1000	6,31	3,15	1,05	0,7
1250	5,73	2,86	0,95	0,64
1500	5,85	2,93	0,98	0,65
1750	5,5	2,75	0,92	0,61
2000	5,24	2,62	0,87	0,58
2250	5,04	2,52	0,84	0,56
2500	4,98	2,49	0,83	0,55

Price(d), d = demand = average rides/bike/day

Table 4.13: Case 1: large scale pricing

Finally, the existence of multiple players within one city can be evaluated in this best case scenario. Assuming that e.g. 2.500 bikes of the station-based system in Antwerp can be replaced by free-floating bikes, generating 4,5 rides/bike/day as well, then the total potential market equals 4.106.250 rides per year.

Assuming fair and perfect competition, it can be calculated how many players can be viable in this market and with which fleet size. This is done by considering the existing pricing scheme of *DonkeyRepublic*, taking an average of € 2/ride. In this perfect market, 10 players can be viable with fleet sizes ranging from 200 to 400 bikes, or 8 players with fleet sizes from 450 to 550. Anything below this amount of players, would permit in higher profit margins or lower prices for customers.

Considering the competition between small and larger players in a market, the advantage of large scale players can be observed from Table 4.13 as well. At the targeted average demand of 3 rides/bike/day it can be seen that a small player of 500 bikes can set prices at €1,7 per ride, while a larger system of 1.000 bikes can offer the same services at €1,05 per ride. Larger players have thus a significant advantage over smaller operators. The magnitude of the advantage depends on the difference in fleet sizes.

4.6 Conclusion

In the first part of the analysis, the most important levers of hub-centric bike sharing providers were brought to light. Hardware costs can be considered as less important. Most contributing cost categories are related to wage costs for different types of employees. Depending on the fleet size considered, maintenance workers become the most contributing wage cost, followed by operating staff for relocation. The relocation efforts are set at a minimum effort of 3 days performed per week for being able to derive minimum conditions. A last significant contributing factor in the system is the platform cost.

The analysis was made between in-house software development and maintenance on the one hand side and outsourcing software costs to a third party on the other. Over a time horizon of five years, there is little difference between both options. However, outsourcing gives a significant buffer in cash savings against less revenue expected in the first phase of operations. It was demonstrated that a cost of up to around 20% of the revenue generated for outsourcing software, would permit operators to financially opt for outsourcing.

The most important part of the analysis was focused on the scalability of the system. Firstly, scaling up by expanding to multiple cities can not safely or unambiguously be concluded to be positive from this analysis. In some cases it will result in a clear positive scale effect, but there are too many parameters involved to be sure of the effect. It should be evaluated case by case, with good estimations of extra staff needed to operate in other cities.

The scale effect of increasing the fleet size within one city was observed to be clearly positive. The high wage costs do not vary linearly with increasing fleet size and can thus be spread across more vehicles, resulting in a positive effect. The costs per bike decrease significantly up to and even beyond 1.000 bikes. The impact of optimizing the fleet size around an optimum for a fixed market size was found to be negligible. The additional cost of deploying one extra bike, assuming no extra employees should be hired, is only €0,69 per day. This means that the operator should somehow be able to generate an additional €0,69 per day to cover the costs of the extra bike. This is equivalent to or can be translated in a price increase of only 1 cent per 20 extra bikes in the system. So having 20 extra bikes in the system on top of the optimal level, would result in a only 1 cent per ride price increase to cover the costs of this error.

Increasing the fleet size too far to reduce the average cost per bike, makes no sense without considering the demand each bike can generate. Real-life scenarios are created with a limited fleet size and low average demand of 0,5 rides per bike per day. It can be concluded that current providers are not viable at all with current pricing schemes. Depending on the considered fleet size deployed, an average between 1,2 and 2,6 rides/bike/day make the system viable. The target of 3 rides/bike/day can make small systems of 350 bikes already viable.

Finally, the evaluation of a best case scaling up scenario showed the potential of viability for this system. The existence of current station-based large scale bike-sharing systems in cities like Brussels or Antwerp, could be the limiting factor in market size. If FF bike sharing market size could replace the existing SB systems with the same market, cities like Antwerp could permit up to 10 players to deploy up to 500 bikes while all being viable with the current pricing schemes of around € 2 per ride. In such markets, large operators can have a significant advantage in competition with small operators. Depending on the difference in fleet sizes, large operators can permit themselves to offer significantly lower prices which gives them the competitive advantage.

Chapter 5

Case 2: Free-floating e-scooter provider

This chapter will go into depth of the results of the cost model for free-floating e-scooter providers. The cost model is constructed first as explained before. After that, the same steps are followed to perform the techno-economic analysis as done for the bike sharing providers. Sensitivity analysis will discover the most important levers of the system, after which more detailed and targeted scenario analysis can be done. In a final step, current viability of this system in real-life modelling assumptions will be assessed by benchmarking current pricing schemes. Compared to the bike sharing model, this benchmarking will be done for a current, average and best case scenario considering possible improvements in hardware and operational efficiency. The reason for this is because free-floating e-scooter providers have massively gone to market in recent years without the best product nor operations. Improvements are expected and reported. It could be interesting to evaluate the possible impact.

5.1 Cost model

Again, the results of the cost model are dependent on the modelling assumptions. A realistic base case scenario should be set. There are currently three players active in Antwerp with around 200 scooters [73], growing to 300. In Brussels there are several players active on a much larger scale of 1.500 scooters per operator, such as *Dott* and *Lime*. The modelling assumptions for the base case setting are shown in Table 5.1 and are for the small scale scenario of 300 scooters. Starting from there, scale effect will be evaluated up to the size of 1.500, which is the largest scale in Belgium currently.

Model assumptions	**Amount**	**Unit**
Time horizon	5	years
Discount rate	15	%
Inflation rate	2	%
Amount of cities	1	
Fleet size	300	scooters
Warehouse size	0,5	m^2/scooter

Table 5.1: Case 2: modelling assumptions

There are four operation models that will be evaluated compared to each other. These are explained earlier. In this section, only the cost model of option 1, performing charging operations with in-house employees, will be displayed. The cost model is built in the same way for the other three options and can be found in the attached Excel file. Applying the cost modelling framework, this results in the upfront costs shown in Table 5.2 and recurring costs in Table 5.3 for option 1.

Category		**# units**	**Amount [€]**
IT&Marketing	Website		5.000
Administration	Start-up		1.500
Platform	Development		145.500
	Testing		50.925
	Subtotal		**196.425**
Assets upfront	e-Scooters	300	150.000
	Chargers	135	2.430
	Batteries	30	2.850
	SIM-card	300	750
	Subtotal		**156.030**
	Gear		10.000
		TOTAL =	**368.902**

Table 5.2: Case 2: one-off costs

Category		# units	Period	Amount [€]
Assets recurring	e-Scooters	150	month	75.000
	Chargers	6	month	101
	Batteries	0	month	0
	Subtotal		**month**	**75.101**
	Warehouse rent	150	month	1.050
	Van lease	2	month	910
	Subtotal		**month**	**1.960**
IT&Marketing	Web hosting		month	17
	Social media		month	200
	Subtotal		**month**	**217**
Administration	Company contr.		year	350
	Insurances	300	year	15.000
	Subtotal		**year**	**15.350**
Platform	Maintenance	1	month	8.500
Operations	Charging		month	19.970
	Customer supp.	1	month	6.800
	Maint. staff	1	month	6.800
	Repair costs (material)	300	month	6.900
	Payment	27.000	month	1.350
	Subtotal		**month**	**41.820**
MM&Overhead	Manager wage	1	month	10.200
	Marketeer wage	1	month	8.500
	Subtotal		**month**	**18.700**
	Utilities	150	month	45

Table 5.3: Case 2: recurring costs

The total NPV of the costs can be calculated and translated to the annual equivalent worth. The values are given in Table 5.4. Again, the total cost can be split into its categories to discover the overall most important costs as shown in Figure 5.1. Compared to the bike sharing case, the scooter-related recurring costs are the major category in the total cost with 49% in the base case. This is due to the higher purchase price and low life expectancy. Interesting scenarios can be constructed to see the influence of improvements on this aspect. The second largest category is the operational cost representing 27%.

Results	Amount
PV costs (5Y)	€ 8.390.762
AW costs	€ 2.046.429

Table 5.4: Case 2: results of discounted costs

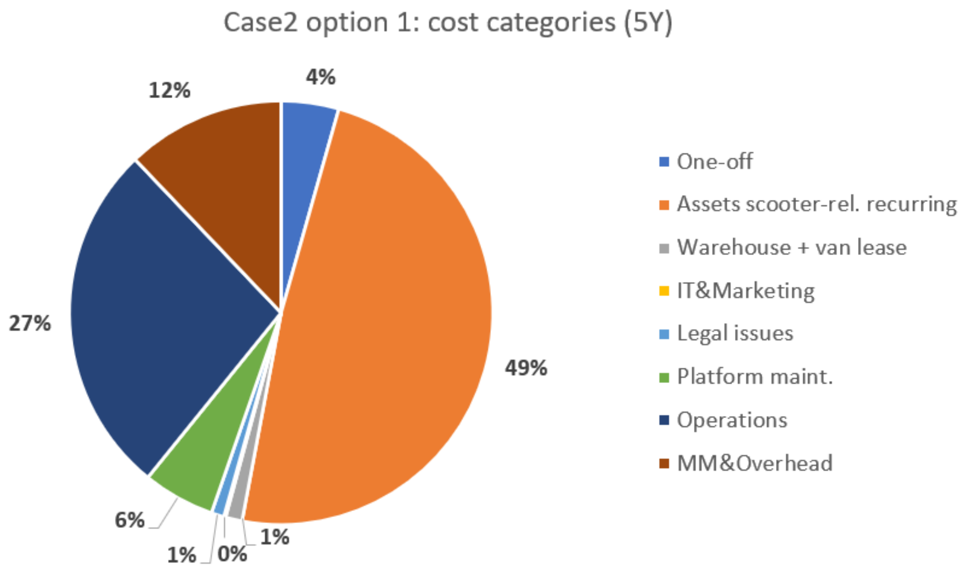


Figure 5.1: Case 2: cost categories based on NPV

Again, for evaluating efficiency of the operations, the proportion of each driver of this cost is shown in Figure 5.2. As expected, the charging operations are the most significant contributor with 48%. Charging operations, when performed in-house as in option 1, are very labour-intensive. As exposed in Chapter 3, the total cost of charging is largely induced by wage costs. The different options for charging will be evaluated thoroughly in the scenario analysis.

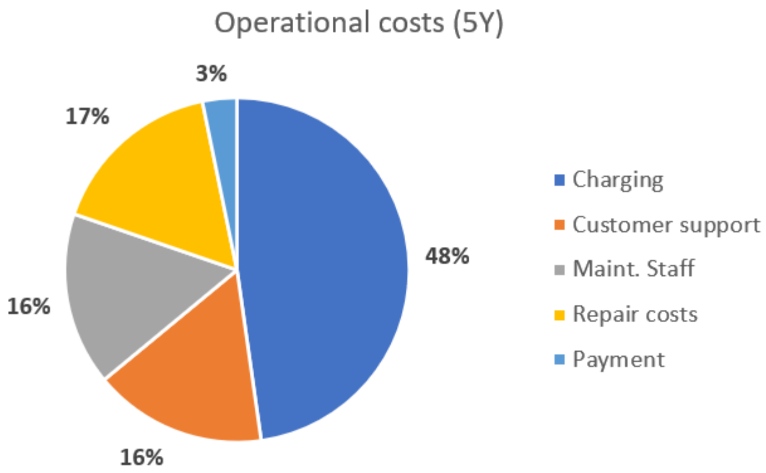


Figure 5.2: Case 2: operational cost categories based on NPV

5.2 Demand input

Primal analysis will be done on the cost structure constructed above. Creating different scenarios by changing parameters will have an influence on the costs. These insights are a first part of the derivation of viability conditions. As in the previous case for the bike sharing providers, a demand input will be coupled to the obtained AW of the costs, to obtain a break-even and operational pricing. Minimum average demand level given the current price setting can also be evaluated.

There is one reported average demand level in Brussels of 3 rides/scooter/day for the large scale provider *Lime* [74]. The average trip length is taken as 10 minutes over an average distance of 1,5 km in Belgium. The average demand is comparable to what American studies report, but the length of the trip is a fraction shorter than the figures used in Table 3.8. In this case, these are important parameters to know since current pricing schemes for scooters are on pay-per-minute basis. The amount of kilometers driven is important to know, to calculate the charging need. The demand parameters are shown in 5.5.

Parameter	**Amount**	**Unit**
Average demand	3	rides/scooter/day
Time duration/ride	10	min
Distance/ride	1,5	km

Table 5.5: Case 2: demand input parameters

5.3 Standard sensitivity analysis

To further evaluate the importance of the different cost drivers or levers in the model, a standard sensitivity analysis is performed. The values of each main cost group were varied from -100% to +100% compared to the base case. The influence on the NPV for each category is displayed in the spider-plot in Figure 5.3.

The recurring scooter-related costs are by far the most significant contributor to the NPV of the costs over this 5 year planning horizon. This was not the case in the bike sharing case and is due to the much higher unit cost of the e-scooters and the very limited life expectancy. These two costs are a hot topic in current developments around e-scooter sharing. The first generation models, which were rolled out the past years, were not developed for shared use. This led to higher purchase prices and scooters being damaged too much. More recent models are being built specifically for shared use which will reduce production cost and increase life expectancy. The current, average and best case scenario considering these improvements will be evaluated.

Besides the hardware costs, charging operations come out as second most important cost in the spider plot. This operation is highly labour-intensive and a result of important operational choices. As mentioned earlier, charging operations can be done in-house or outsourced to gig workers. Lastly, the introduction of swappable batteries is mentioned as one of the key drivers to reduce the charging cost. All options will be further evaluated in the scenario analysis.

As in the bike sharing case, platform development and maintenance are a significant cost to the system. Possibilities to outsource all software-related costs are also an option for these providers. However, the analysis on the cost effect is not repeated for this case.

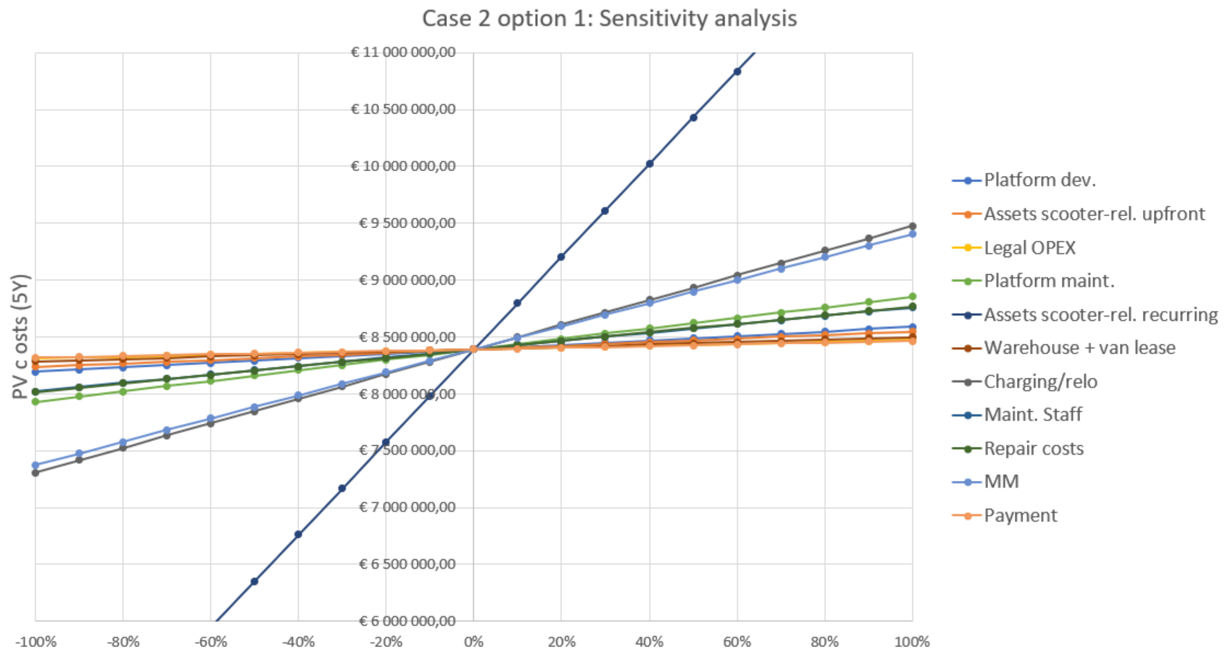


Figure 5.3: Case 2: sensitivity analysis of cost categories on NPV

5.4 Scenario analysis: impact of generic levers

The next step in deriving viability conditions is to set up well-chosen scenarios. The impact of changing important levers on the cost will be evaluated primarily. Once the impact is known, real-life use cases will be constructed to evaluate the existing pricing schemes. Different scenarios will permit to derive the needed combination of parameters to result in a sustainable and profitable business.

5.4.1 Charging costs

As discussed in Chapter 3, there are initially four different charging options considered. These are in-house charging, charging by gig workers, a combination of in-house and gig workers and lastly charging by in-house employees with swappable batteries. From the evaluation of option 3, being a combination of in-house and gig workers, it was shown that this option is highly dependent on the proportion performed by each option. In practice, this proportion is hard to estimate and will depend from case to case. For this reason, this option will be omitted in the remainder of the analysis.

The different charging options will be discussed further over all sections in the analysis. This will be done by always displaying the impact of changing a cost driver for all options simultaneously in the plots. From these plots, it can be easily seen which option performs best under which assumptions.

5.4.2 Hardware costs

Considering the hardware costs in the system, there are three relevant cost drivers that could be very influential and on which improvements have been discussed in literature. These are the life expectancy of the scooters, the production cost and the battery capacity. The impact on the cost is discussed below. A current, average and best case scenario can be constructed to evaluate the impact on pricing by adapting these levers together.

5.4.2.1 Life expectancy

In the base case scenario, the current life expectancy of shared e-scooters is set at two months. This is the current and worst case scenario, aiming to lengthen the life span. The average improvement that one can expect in the short term by adapting the design should be around six months. In the best case, operators could aim for a life span of up to one year. The effect of ranging the life span from the current to best case scenario on the AW of the costs is shown in Figure 5.4.

Improving the life expectancy to up to six months, compared to the base case of two months, reduces the AW of the costs up to around 30% in all three operational options. This is very significant and can therefore be considered as an important lever for financial viability. Costs can in the most optimistic scenario of 12 months even be reduced 8% more. This drastic cost reduction can result in price decreases or larger profit margins. The effect on the price will be discussed in the use case section. However, it is already clear that life expectancy is a major driver towards viability.

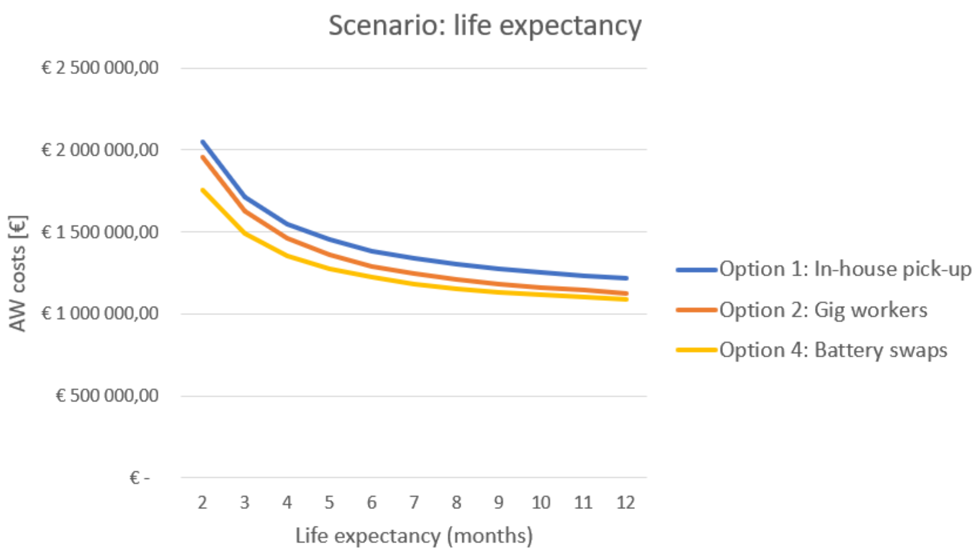


Figure 5.4: Case 2: impact of scooters' life expectancy

Life expectancy	AW costs [€]	Abs. diff.*	Rel. diff.*
Option 1: in-house pick-up			
2 months	2.046.429		
6 months	1.384.812	661.617	-32%
12 months	1.219409	827020	-40%
Option 2: gig workers			
2 months	1.954.788		
6 months	1.293.172	661.617	-34%
12 months	1.127.768	827.020	-42%
Option 4: in-house swap			
2 months	1.758.326		
6 months	1.222.417	535.909	-30%
12 months	1.088.439	669.886	-38%

*Difference from base case scenario of 2 months

Table 5.6: Life expectancy e-scooters

5.4.2.2 Production cost

Production or purchase cost for new e-scooters are quite high compared to buying bikes. In the base case scenario the cost is set at €500. The impact of this cost is high because of the short life expectancy. It is expected that these costs can be lowered by mass production and a more sustainable design developed for shared use. In the best case scenario it is believed that production costs could be lowered to €300 a piece [54].

The impact on the AW of the costs by changing this cost is plotted in Figure 5.5 and the values for the three selected scenarios (current, average, best) are given in Table 5.7. The costs are logically a decreasing linear function of the production cost. The AW of the costs decreases for all operational models around 10% per €100 decrease in production cost. It can again be concluded that this will have a considerable effect on the financial viability. Effect on pricing will be done in combination with the other hardware improvements in a later section.

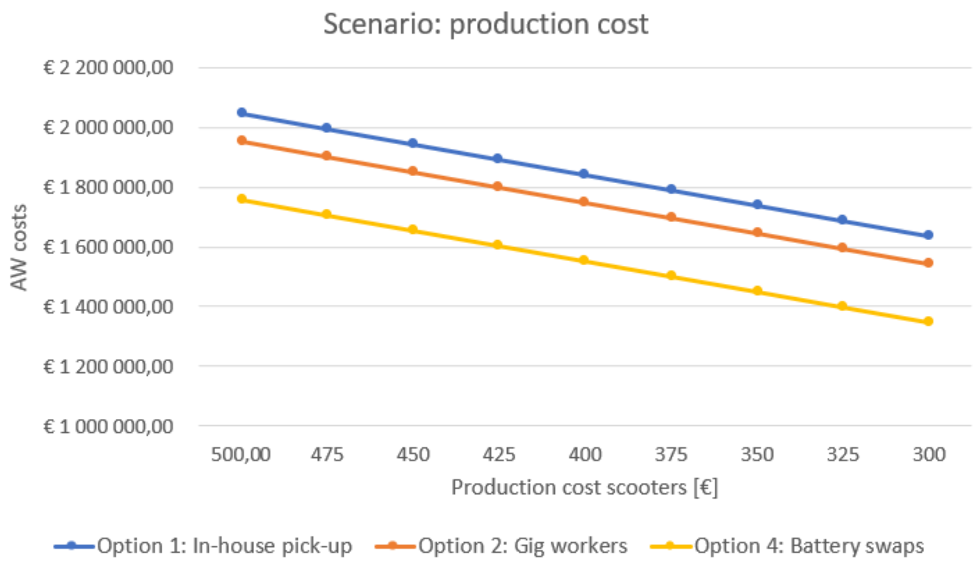


Figure 5.5: Case 2: impact of scooters' production cost

Production cost [€]	AW costs [€]	Abs. diff.*	Rel. diff.*
Option 1: in-house pick-up			
500	2.046.429		
400	1.840.627	205.802	-10%
300	1.634.826	411.603	-20%
Option 2: gig workers			
500	1.954.788		
400	1.748.986	205.802	-11%
300	1.543.189	411.603	-21%
Option 4: in-house swap			
500	1.758.326		
400	1.552.524	205.802	-12%
300	1.346.723	411.603	-23%

*Difference from base case scenario of €500

Table 5.7: Production cost e-scooters

5.4.2.3 Battery capacity

Finally, considering the hardware of the scooters, the battery capacity is said to be a possible parameter for improvement. Capacity could be increased for the new generation scooters to 150% of current capacity. The impact of this parameter will result in this model in a decreased frequency of charging need. In Figure 5.6 it can be seen that the effect can only be seen at certain capacities, for example at 110% for all operational options. The effect is thus negligible in quite large ranges and is thus for this reason not considered as a major contributor to the impact on financial viability. The combination of a better and more sustainable design leading to longer life expectancy and decreased purchase cost are more important.

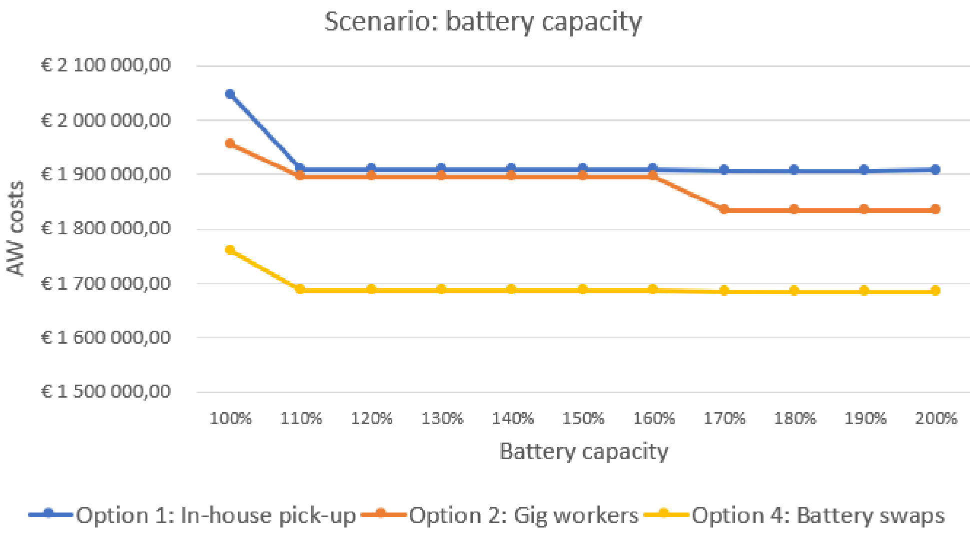


Figure 5.6: Case 2: impact of scooters' battery capacity

5.4.3 Scalability

In the base case scenario, a fixed fleet size of 300 scooters is assumed. An important measure is again the effect of scalability. For these more expensive vehicles, one can ask the question again whether it is worth to deploy one more scooter. By scaling up, the fixed costs can be spread over more units, while more units also induce more variable costs. As done in the bicycle sharing case, the effect of scaling could be studied over multiple cities. However, this analysis was not done, because the same conclusions could be drawn. With the constructed cost model, more valuable results can be drawn by looking at the effect of being active at small scale compared to being active at large scale within a city. Currently in Belgium, there are some small scale initiatives trying to survive next to the larger foreign companies.

5.4.3.1 Scalability within one city

In Figure 5.7, the fleet size is varied from 300 to up to 2.000 e-scooters. This coincides with the smallest and largest fleet sizes active in Belgium at the time being. Increasing the fleet size increases the annual worth of the costs. For all systems, there is a clear positive scale effect to be seen on the average cost per scooter. Costs that are independent from the fleet size, such as wage and platform costs, can be spread over more units.

It can be seen that option 4, system with swappable batteries, is the least expensive option and the annual worth grows less fast with increasing fleet size. The positive scale effect is large up to around 1.000 scooters and then the curve flattens and seemingly only minor gains are possible by further increasing. Lastly, the option 1 with in-house employees will always be more expensive than working with gig workers. However, the larger the fleet size, the closer these two options become in pricing. It would thus be advisable to perform charging operations with in-house employees, because there is more control over the operations.

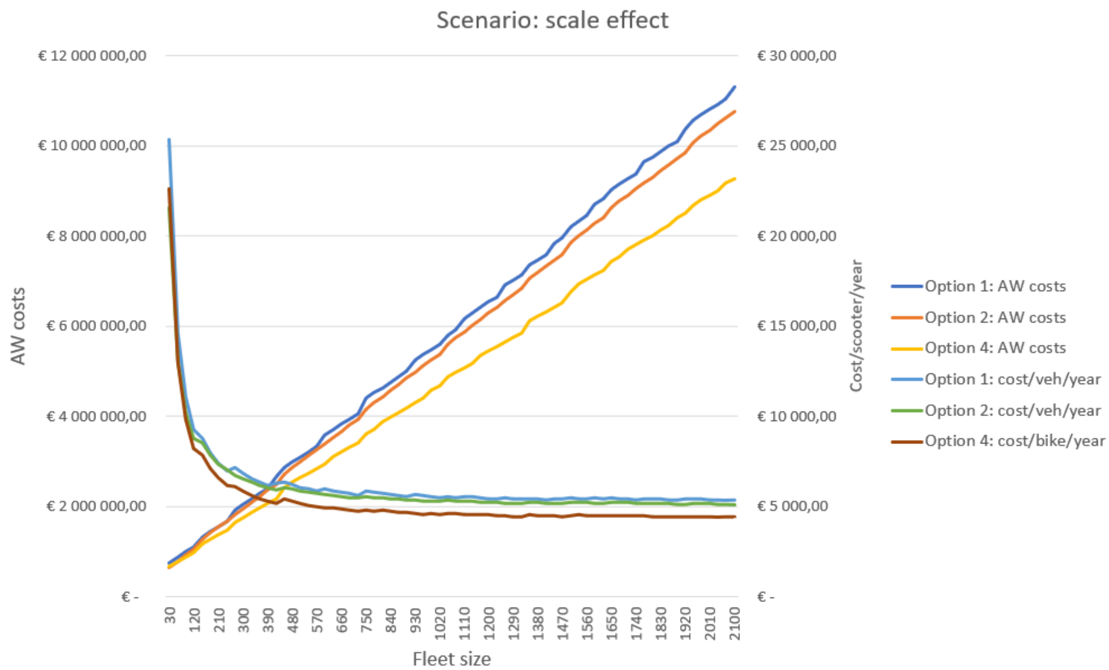


Figure 5.7: Case 2: positive scale effect within one city

Fleet size	Cost/scooter/day [€]	Reduction*
300	18,69	
450	17,43	7%
600	16,38	6%
750	16,09	2%
900	15,20	6%
1.050	15,15	0%
1.500	14,99	1%
2.000	14,74	2%

*Cost reduction compared to previous fleet size

Table 5.8: Case 2: scale effect

In Table 5.8, some values of the cost curves are given. Starting from the small scale of 300 scooters up to 900, the positive scale effect is visible in the percentage decreases of the daily costs per scooter up to 6%. When expanding further beyond 1.000 scooters, this reduction stays around 0-1%. Again, the effect of thorough planning and fleet size optimization can be an important business insight for these providers.

Figure 5.8 shows the marginal cost per day of adding scooters to the system together with the effect on break-even pricing for a fixed market size of 1.500 rides/day. The marginal daily cost for adding one scooter is €10,55, which is much larger than in the bike sharing case. This is evidently due the higher purchase prices. Because of the discrete modelling assumptions for maintenance and charging staffing, at certain levels the marginal daily cost peaks with a value of €257. Translating this into break-even pricing, this would result in a 1 cent increase in price per minute for every 13 additional scooters. A fleet size error of 65 scooters compared to the optimal level would thus result in a price difference of 5 cents per minute. This price difference seems low, but the effect has to be evaluated at the break-even pricing of the considered scale. If the considered scale results in a price per minute of 25 cents, then 65 too many scooters results in a price increase of 20% which is significant. Care should be taken with this optimization by the presented magnitude.

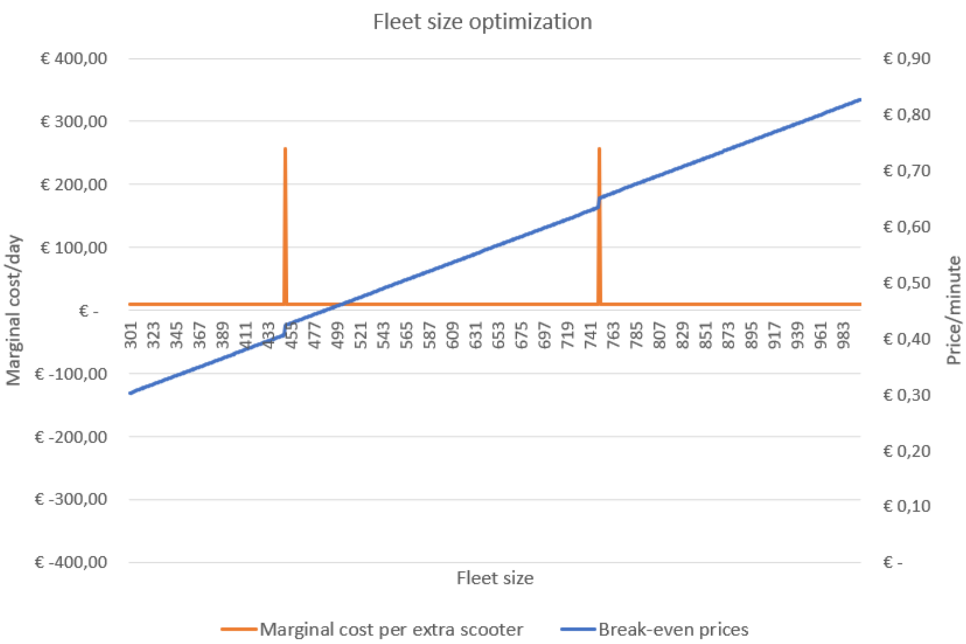


Figure 5.8: Case 2: marginal cost curve

5.5 Use cases: pricing and demand comparison

The most important levers in the e-scooters cost model have been discussed at this point. The cost model can now serve to analyze the performance of current operational companies primarily in Belgium. As explained, the viability of small-scale start-ups will be discussed first. By doing this, it can be evaluated whether it is viable to keep operating at small scale in the long term in typical Belgian cities or not. This will be done by coupling the average demand input to the cost model and benchmarking the derived price setting to existing pricing schemes.

Next, larger scale systems in cities like Brussels will be considered and evaluated. Companies that are active on this scale are large leaders such as *Lime*, *Bird* or *Circ*. The effect on the unit economics can be studied compared to operating at smaller scale.

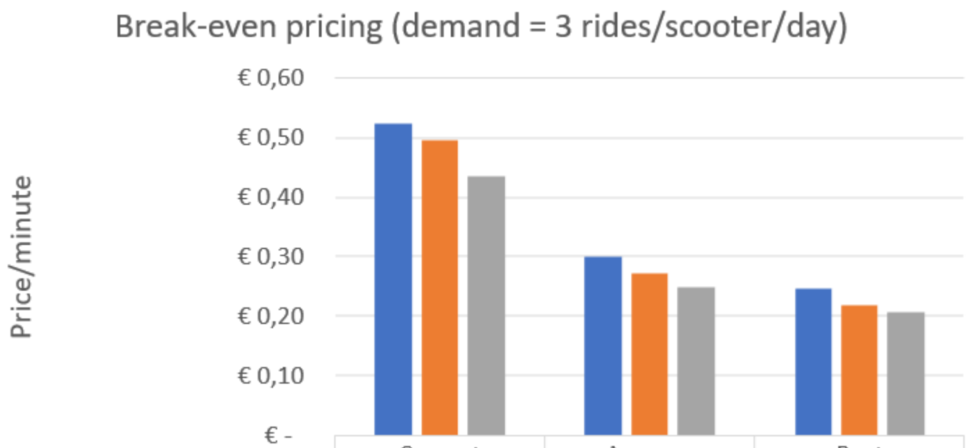
5.5.1 Current small scale systems

The set-up of the cost model in the base case assumes a small-scale start-up of 300 scooters in one city. It can be evaluated whether and under which conditions small scale systems can be viable in the long term. As explained, this will be done for the current, average and best case improvements on the hardware of the scooters. It must be noted that no such small scale operators are active currently in Belgium, operating only e-scooters. However, there exist possibilities to own such fleets by cooperating with larger players. That's why this analysis could be of interest. The set-up of the different scenarios are shown in Table 5.9.

Input parameter		**Amount**	**Unit**
Fleet size		300	scooters
Demand		3	rides/scooter/day
Production cost	Current	500	€
	Average	400	€
	Best	300	€
Life expectancy	Current	2	months
	Average	6	months
	Best	12	months

Table 5.9: Case 2: small scale scenario modelling inputs

Current pricing schemes adopted by providers worldwide make use of a pay-as-you-go model with a fixed fee of €1 to unlock a scooter. The per minute fee varies from 20 cents to 30 cents. The obtained break-even pricing for the different scenarios are shown in Figure 5.9. This is for the average base case demand of 3 rides per scooter per day. With the current expensive and rapidly breaking down scooters, the system is not viable with a demand of 3 rides per scooter per day. In the average case scenario with the possible and realistic improvements, the obtained prices lie in the interval of current pricing schemes. When moving to the best case scenario, option 4 with swappable batteries is the only operational model that meets the minimum pricing scheme of 20 cents per minute. It is clear from the results that converting the fleet into scooters with swappable batteries results in lower costs and pricing. The charging operations are significantly less labour-intensive and permit to lower prices.



	Current	Average	Best
Option 1: In-house pick-up	€ 0,52	€ 0,30	€ 0,25
Option 2: Gig workers	€ 0,50	€ 0,27	€ 0,22
Option 4: Battery swaps	€ 0,44	€ 0,25	€ 0,21

Figure 5.9: Case 2: price setting in different scenarios

The evolution of demand for these types of vehicles is difficult to predict. It is not sure whether this average of 3 rides per scooter per day is representative for a mature and satisfied market. For completeness, the minimum demand input needed to break even with current pricing schemes is sought in Figure 5.10. It can be read from the table that the models with charging by in-house employees or gig workers under current circumstances can only be viable at a demand of 4.5 rides/scooter/day if customers are willing to pay up to 30 cents per minute. For the operational model with swappable batteries, providers can already be viable from 4 rides per scooter per day.

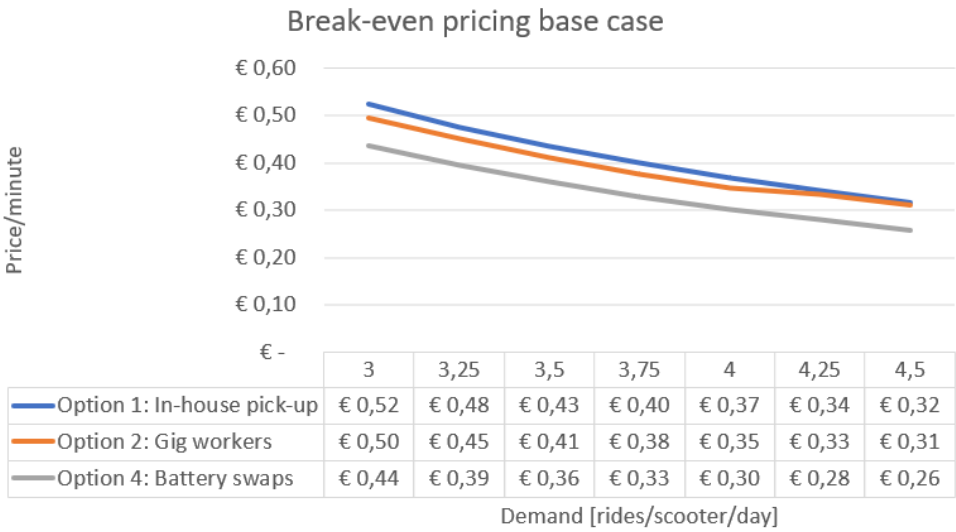


Figure 5.10: Case 2: price setting for varying demand inputs

5.5.2 Best case scaling up scenario

Finally, large scale operating providers are evaluated. It can be interesting to evaluate from which point the positive scale effect is not visible anymore in the obtained pricing. The price evolution for increasing fleet size in the base case scenario with an average demand of 3 rides/scooter/day is shown in Figure 5.11. It can be observed for all operational models that the price starts stagnating around 1.000 scooters. Increasing fleet sizes further should only be done if they can generate additional revenue by meeting the average demand level. Looking at the figures, only option 4 with swappable batteries comes close to being viable with the current maximum rate of 30 cents per minute, under the condition that it operates up to 2.000 scooters.

At the level of 1.500 scooters, which is more or less the largest active fleet size in Belgium at the moment, switching to scooters with swappable batteries can decrease the costs or resulting prices by 22% compared to option 1. Almost the entire benefit is due to more efficient charging operations. Another part is due to the longer lasting battery lives that can be swapped from a damaged scooter to a new scooter.

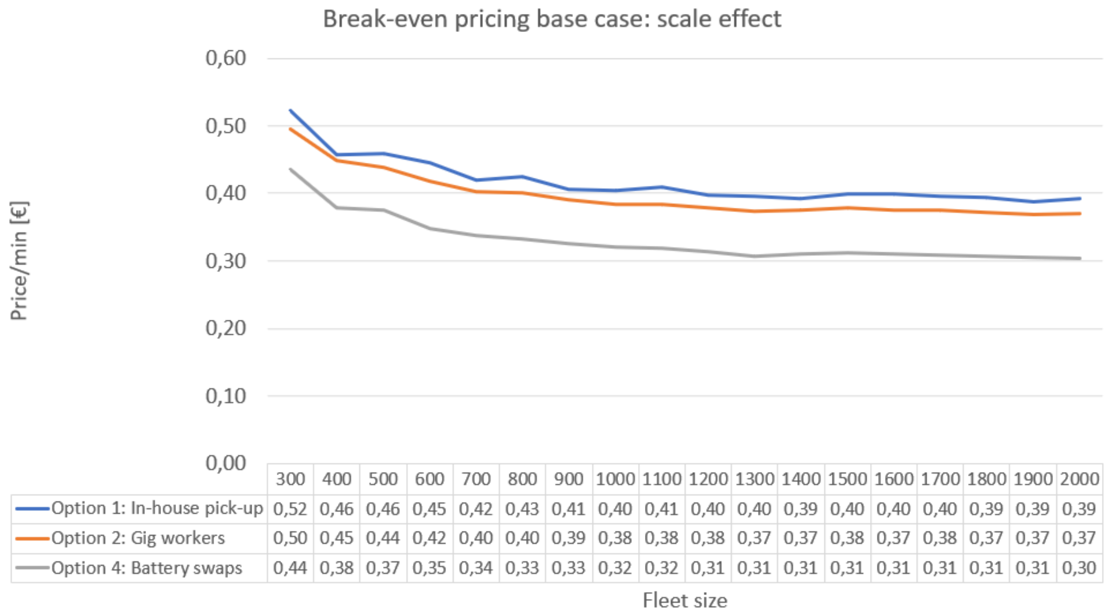
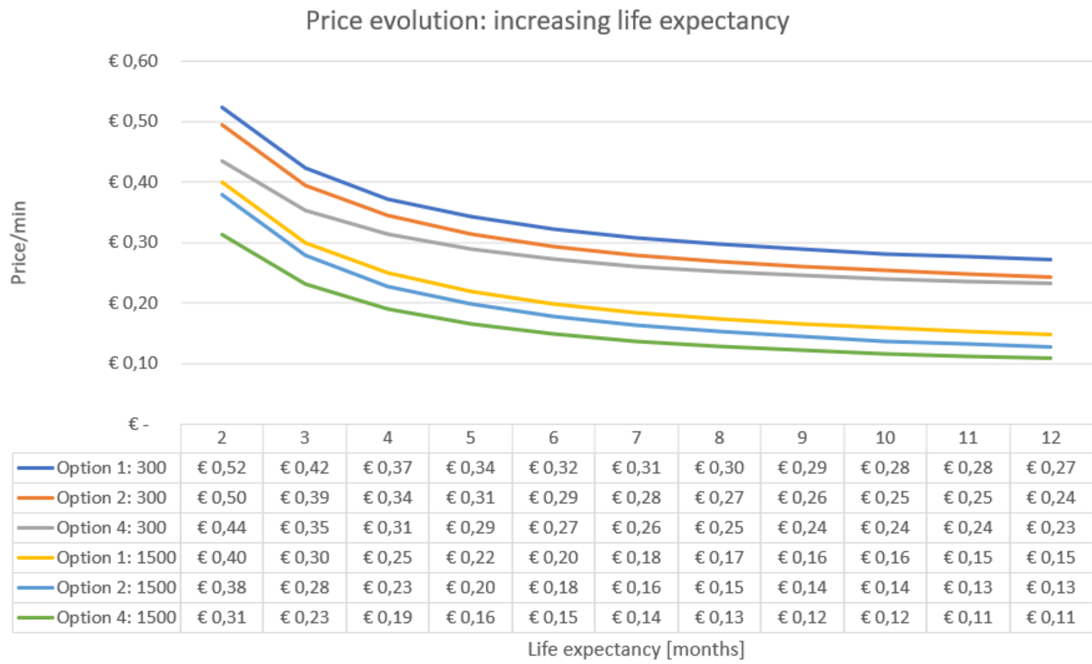


Figure 5.11: Case 2: price setting for varying fleet size

Not the demand, but improvements in hardware and operations are expected to enhance the unit economics. Before evaluating the average and best case scenario, the effect on break-even pricing for only varying the life expectancy is considered while keeping production cost at €500. This is done to be able to discover whether it is possible to be viable with only changing this factor in between the limits of the average and best case scenario.

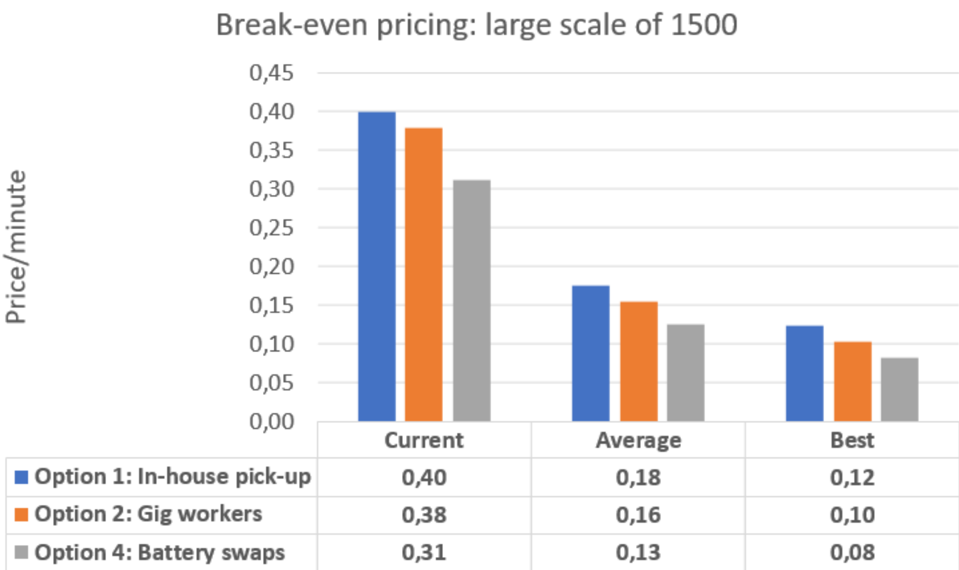
The price per minute for a small scale and large scale scenario of respectively 300 and 1.500 scooters with an average demand of 3 rides/scooter/day is shown in Figure 5.12. For the small scale system, all three options become viable when only improving the life expectancy of the scooters to 8 months. For option 4 this is even possible from 5 months, which is a clear indication again that operating with swappable batteries in the future is the best option. At the larger scale of 1.500 scooters, providers can be viable in the current pricing zone when increasing the life expectancy between 3 to 6 months for all options. The minimum of 20 cents per minute for option 4 is already reached when increasing life expectancy only to 4 months.

Combining the life expectancy with the reduced production cost into the current, average and best case scenario for a fleet size of 1.500 is shown in Figure 5.13. In the average targeted case, break-even prices for all options drop below 20 cents per minute, which is the current minimum pricing scheme. This is a strong indication for the viability and sustainability of e-scooter sharing providers. Improving even further can reduce prices or increase profit margins significantly.



	2	3	4	5	6	7	8	9	10	11	12
Option 1: 300	€ 0,52	€ 0,42	€ 0,37	€ 0,34	€ 0,32	€ 0,31	€ 0,30	€ 0,29	€ 0,28	€ 0,28	€ 0,27
Option 2: 300	€ 0,50	€ 0,39	€ 0,34	€ 0,31	€ 0,29	€ 0,28	€ 0,27	€ 0,26	€ 0,25	€ 0,25	€ 0,24
Option 4: 300	€ 0,44	€ 0,35	€ 0,31	€ 0,29	€ 0,27	€ 0,26	€ 0,25	€ 0,24	€ 0,24	€ 0,24	€ 0,23
Option 1: 1500	€ 0,40	€ 0,30	€ 0,25	€ 0,22	€ 0,20	€ 0,18	€ 0,17	€ 0,16	€ 0,16	€ 0,15	€ 0,15
Option 2: 1500	€ 0,38	€ 0,28	€ 0,23	€ 0,20	€ 0,18	€ 0,16	€ 0,15	€ 0,14	€ 0,14	€ 0,13	€ 0,13
Option 4: 1500	€ 0,31	€ 0,23	€ 0,19	€ 0,16	€ 0,15	€ 0,14	€ 0,13	€ 0,12	€ 0,12	€ 0,11	€ 0,11

Figure 5.12: Case 2: price setting for varying life expectancy



	Current	Average	Best
Option 1: In-house pick-up	0,40	0,18	0,12
Option 2: Gig workers	0,38	0,16	0,10
Option 4: Battery swaps	0,31	0,13	0,08

Figure 5.13: Case 2: price setting in different scenarios at large scale

Finally, the existence of multiple players within one city can be evaluated in this best case scenario. Assuming that the maximum observed amount of 5.000 scooters in Brussels can all generate the average of 3 rides per scooter per day, then the total market size is

15.000 rides per day.

Assuming fair and perfect competition, it can be calculated how many players can be viable in this market and with which fleet size. This is done by looking at the break-even pricing compared to the current zone of 20 to 30 cents per minute. In this perfect market, up to 8 players with a limited fleet size of 300 scooters can coexist. Considering the presence of multiple multinational players like *Lime*, *Bird* or *Dott*, it is derived from this model that only 2 players can coexist at this scale at current pricing. Comparing the competitiveness between small and large players within the same micro-market, the break-even pricing indicates an advantage in pricing of around 40% for large players, which is significant.

5.6 Conclusion

The standard sensitivity analysis of this free-floating e-scooter sharing system permitted to discover the most important levers or cost drivers. As expected by the indication of other studies, the largest contributor to the total cost are the recurring scooter-related hardware costs. Charging operations came out as the second most important cost. From all operations, this is the most labour-intensive job. Finally, the development and maintenance of an online platform for the distribution of the system was indicated as an important cost driver. It must be noted that the difference between in-house and outsourcing software costs was not evaluated in this use case. However, similar conclusions could be drawn and outsourcing is definitely an option to consider for these type of providers.

Considering the hardware of the e-scooters, possible improvements suggested in literature were implemented and evaluated. Increasing the life expectancy from 2 to 6 months led to a cost reduction of around 30%, while increasing it to the best case suggested scenario of 12 months even reduces it further to 40%. It can safely be concluded that life expectancy of the scooters is a major contributor to financial viability for these providers. A second major contributor is the purchase price (or production cost) of the e-scooters. Decreasing the production cost up to €300 is a parameter which should be evaluated with care since no proof exists that this will be possible. However, if decreasing production costs would be possible in the future, 10% cost reduction is possible per €100 production cost decrease.

The scale effect of increasing the fleet size within one city was observed to be positive and significant up to around 1.000 scooters. The impact of optimizing the fleet size is again an important aspect to consider here. The marginal cost per day of adding one extra scooter to the fleet was calculated as €10,55, except from the points where more employees are needed. Translating this marginal cost to the effect in break-even pricing resulted in a 1 cent price increase per 13 extra scooters or equivalently 5 cents per 65 scooters. Considering current pricing schemes between 20 and 30 cents per minute, this could thus lead to a 20% price increase. Thorough planning can thus be advised with the demonstrated magnitude.

Finally, specific small and large scale use cases were evaluated that should represent operators being active in Belgian cities. The small scale of 300 scooters should reflect start-ups, while the larger scale of 1.500 reflects the maximum observed fleet size in Brussels. In the base case with an average demand of 3 rides per scooter per day, the small scale system can not become viable by scaling up. Increasing life expectancy for the small scale up to 8 months makes the system viable, while at 1.500 scooters this is possible from 3-6 months. Looking at the competition in a market like that of Brussels, only two possible players at the large scale would be viable. Again, the advantage of large players is significant when looking at the break-even pricing. Pricing differences when comparing a fleet size of 500 and 1.500 scooters can be more than 10%.

Charging operations were evaluated over all scenarios. In all plots, it can be seen that working with gig workers is slightly cheaper than with in-house employees, but the difference in pricing is negligible. Working with in-house employees would thus be advisable to have better control over the operations. Relying on gig workers could result in high fluctuations of the amount of scooters charged each day, while with in-house employees the desired state of the system can assured at all times for a slightly higher price. Switching the fleet to vehicles with swappable batteries, as demonstrated in option 4, can reduce the costs significantly and outperforms current practices. At the level of 1.500 scooters, a cost and price decrease of 22% is possible. Switching to these more efficient operations could thus be a major key driver towards viability.

Chapter 6

Conclusions

The rise of new mobility service providers under the concept of MaaS is an interesting evolution in the mobility landscape. Innovations and a growing market for micro-mobility providers have attracted many investors and lots of fund raising has boosted their business. It is observed that the existing literature on shared mobility and MaaS has a strong focus on specific aspects of the operations such as relocation optimization and planning and on issues regarding regulating these innovative services. However, there is a lack of decent financial assessment of the entire business for operationally active mobility providers. Hence this work is an addition to the existing literature by the assessment of existing systems and deriving minimum financial viability conditions from a techno-economic point of view.

Out of a possible set of MSPs, it was opted to select hub-centric bike sharing and free-floating e-scooter providers as use case. The reason for this was twofold. First of all, these two types can be categorized under recent and innovative mobility solutions. The hub-centric model combines the advantages of both station-based and free-floating services, while free-floating e-scooters are on a rise around the globe. Secondly, this work was faced with some limitations on available data. This could be coped with by constructing a dynamic excel model in which critical parameters could be adapted. These restrictions were limited for the two considered use cases and thus good conclusions could be drawn.

For both use cases, a dynamic cost model was constructed first as a basic tool to perform the techno-economic analysis. This model includes all detailed cost figures that the companies are faced with. Relocation costs were identified as the most complex cost to model for the bike sharing provider. Different options were explored and a static operator-based strategy was implemented. The analysis of the relocation cost modelling in this context learned that it was almost entirely induced by wage costs and thus by setting the amount of FTEs to deploy and amount of days to perform. The results of this work are under these assumptions, but can be adapted for other use cases. For the e-scooter providers, charging operations were most complex to model. Based on the demand input and battery consumption, the amount of vehicles to charge is calculated. Then there were four different charging options identified and implemented. These are charging by in-house employees, hiring gig workers to perform charging for a fixed fee, a combination of the previous two options and lastly by in-house employees performing battery swaps. All generic, fixed and specific inputs are put into a discounted cash flow model with a discount rate of 15% and a planning horizon of 5 years.

The total discounted cost for the bike sharing provider case was calculated about €2,7 million or translated to an AW of the costs of €800.000. As expected, the operational costs were observed as the major cost group. The sensitivity analysis indicated relocation and platform costs as the most important cost drivers, besides the wage costs for maintenance and management. The outcome of the different scenarios are summarized below. They can be interpreted as the viability conditions and recommendations to existing providers.

- The possibility to outsource software costs was evaluated. For the planning horizon of five years it was concluded that outsourcing software can be the cheaper option of less than 20% of generated revenue should be paid to the software providers. This is the same factor that is applied by an existing firm.
- Increasing life expectancy of the scooters did not seem to have a noticeable impact on the costs and will not be a determining factor for viability of these systems.
- The most important take-away from this analysis is on the scalability of the system, which is observed to be positive up to around 1.000 bikes. The marginal cost per day of adding one bike to the system is estimated to be €0,69, which results in a price increase of 1 cent per 20 extra bikes. The optimization of the fleet size is thus of less importance for planners.
- Looking at the viability of current providers, increasing demand will be a crucial factor. Current average demand of 0,5 rides per bike per day can not make the system viable at any fleet size with current pricing schemes of €1,7-2,2 per ride. An average of 3 rides/bike/day should be targeted to make a fleet size of around 350 bikes viable. For increasing fleet sizes, this can be lowered to 1,2 to 2,6 rides/bike/day depending on the considered fleet size.
- Finally, considering the competitiveness between large and smaller players, price differences can become significant by enlarging the difference in fleet size. This could

result in large players consolidating markets and absorbing small start-ups if no proper regulation on permits is made in cities.

The total discounted cost for e-scooter providers over the planning horizon of five years is significantly larger and estimated to be €8,4 million or an annual worth of €2 million. This is largely due to the higher purchase price and recurring costs for replacement of e-scooters as indicated by the sensitivity analysis. Charging costs were indicated as a major cost driver as well. The results of the scenario analysis in the form of conditions and recommendations for e-scooter providers are summarized below.

- With a life expectancy of 2 months, 49% of the TDC is due to scooter-related recurring costs. Small scale operators with a fleet size of 300 can become viable at current pricing schemes of €0,2-0,3, when only increasing the life span to around 8 months. Looking at the larger scale systems in Belgium of 1.500 scooters, they can already become viable when only increasing life expectancy of the scooters to 3-5 months. Life expectancy of the e-scooters is thus considered as the primal driver towards viability.
- Another hardware aspect is the production or purchase cost of the scooters. It is believed that this could be lowered by mass production. A 10% cost decrease is estimated in the analysis for every €100 production cost reduction.
- The scale effect on the costs was clearly positive as for the e-scooter providers up until the point of around 1.000 scooters. However, the marginal cost per day of adding an extra scooter to the system, under current circumstances, is estimated as €10,55 or translated to a 5 cent per minute price increase for every 65 extra scooters. Comparing this to the current pricing schemes of €0,2-0,3, this would mean a price increase up to a 20%. Care should thus be taken with the optimization of the fleet size with this magnitude.
- Looking at the viability of current providers, the obtained break-even pricing is compared to the existing pricing schemes at the base case average demand of 3 rides per bike per day. A current, average and best case scenario was constructed to evaluate the break-even pricing based on the hardware improvements. For the base case scenario at a small scale of 300 scooters, operators can not be viable with current pricing, since break-even pricing was estimated around 50 cents per minute. Moving to the average case, with a life expectancy of 6 months and purchase cost of €400, already makes it viable when charging 30 cents per minute.
- Considering the charging operations, currently most systems do this by in-house employees or gig workers picking up scooters to charge them overnight. The more

efficient option with in-house employees swapping empty batteries in the field is gaining ground. Over the entire analysis, this option was observed to be indeed more cost efficient. At the scale of 1.500 scooters it estimated to result in a 22% cost reduction compared to the other options. This last improvement can thus be an extra driver towards viability.

The conclusions in this work indicate the potential of hub-centric bike sharing providers and free-floating e-scooter providers by giving the minimum conditions for viability. For the bike sharing case, this work contributes to the literature by giving an assessment of existing schemes rather than planning on a higher level. Tangible measures are derived that can be used in future recommendations. For the e-scooter case, this work has taken the analysis of the unit economics a step further. Instead of considering only major groups of costs, an entire cost model incorporating all relevant costs a company is faced with was constructed. This addition gives the reader a more realistic view on the economics for these providers.

Future work on this topic could be to enlarge the scope to operators being active with multiple types of vehicles. For example e-bikes or electrical mopeds were introduced and classified as other micro-mobility providers that gain attention. The impact of combining these services by the same operator through a unified platform could result in a different cost structure. In addition to this, the impact of offering the services to a MaaS provider could be studied. As explained, this MaaS provider can bundle the shared mobility services together with others into a single mobility package. The incentive for MSPs to do this would be because of increased demand. If the impact on this change in demand would be known, detailed analysis and reevaluation of prices can be made.

In this thesis, assumptions were made on a lot of data input. For this reason it was chosen to make a dynamic *Excel* model where input can be changed. For example for estimating relocation and charging costs, a general method was applied and implemented. It would be interesting in the future to collaborate with existing operators, which was not possible at the time this work was written. In such collaboration, historical data on demand, usage patterns and other relevant costs could be shared. This would permit to construct a statistical cost model in which parameters are given a certain distribution. This work would greatly benefit from such collaborations to get more insights into complex aspects and to derive more specified and accurate conditions.

Bibliography

[1] M. Kamargianni and M. Matyas, "The business ecosystem of mobility-as-a-service," *96th Transportation Research Board (TRB) Annual Meeting, Washington DC*, no. January, pp. 8–12, 2017.

[2] EMTA, "Mobility as a Service: A perspective on MaaS from Europe‘s Transport Authorities," 2019.

[3] D. Schellong, P. Sadek, C. Schaetzberger, and T. Barrack, "The Promise and Pitfalls of E-Scooter Sharing," 2019. [Online]. Available: https://www.bcg.com/publications/2019/promise-pitfalls-e-scooter-sharing.aspx

[4] J. Rose, D. Schellong, C. Schaetzberger, and J. Hill, "How E-Scooters Can Win a Place in Urban Transport," 2020. [Online]. Available: https://www.bcg.com/publications/2020/e-scooters-can-win-place-in-urban-transport.aspx

[5] S. Shaheen, A. Cohen, and I. Zohdy, "Shared Mobility: Current Practices and Guiding Principles," U.S. Department of Transportation, Tech. Rep., 2016.

[6] DonkeyRepublic, "The hub-centric model - Donkey Republic bike-share for cities." [Online]. Available: https://cities.donkey.bike/bike_share_hub-centric-model/

[7] D. Holland-Letz, M. Kässer, B. Kloss, and T. Müller, "Mobility startup and investment trends 2019," 2019. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/start-me-up-where-mobility-investments-are-going

[8] T. Möller, A. Padhi, D. Pinner, and A. Tschiesner, "The future of mobility 2020," 2019. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-mobility-is-at-our-doorstep

[9] Y. Wang, "How China's Bike-Sharing Startup Ofo Went From Tech Darling To Near Bankruptcy," 2018. [Online]. Available: https://www.forbes.com/sites/ywang/2018/12/20/

how-chinas-bike-sharing-startup-ofo-went-from-tech-darling-to-near-bankruptcy/#3e4fd65466e6

[10] D. Holland-Letz, M. Kässer, B. Kloss, and T. Müller, "Sizing the micro mobility market — McKinsey," 2019. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/micromobilitys-15000-mile-checkup

[11] K. Kokalitcheva, "E-scooter startup Lime shuts in 12 markets, lays off around 100," 2020. [Online]. Available: https://www.axios.com/

[12] C. Mulley, "Mobility as a Services (MaaS)–does it have critical mass?" *Transport Reviews*, vol. 37, no. 3, pp. 247–251, 2017.

[13] Y. Li and T. Voege, "Mobility as a Service (MaaS): Challenges of Implementation and Policy Required," *Journal of Transportation Technologies*, vol. 07, no. 02, pp. 95–106, 2017.

[14] S. Sarasini, J. Sochor, and H. Arby, "What characterises a sustainable MaaS business model?" *1st International Conference on Mobility as a Service (ICOMaaS)*, no. November, p. 15, 2017.

[15] D. A. Hensher, "Tackling road congestion – What might it look like in the future under a collaborative and connected mobility model?" *Transport Policy*, vol. 66, no. February, pp. A1–A8, 2018.

[16] I. C. Karlsson, J. Sochor, and H. Strömberg, "Developing the 'Service' in Mobility as a Service: Experiences from a Field Trial of an Innovative Travel Brokerage," *Transportation Research Procedia*, vol. 14, pp. 3265–3273, 2016.

[17] J. F. Moore, "A New Ecology of Competition," *Harvard Business Review*, vol. 71, no. 3, pp. 75–86, 1993.

[18] Verna Allee, "Value network analysis and value conversion of tangible and intangible assets," *Journal of Intellectual Capital*, vol. 9, pp. 5–24, 2008.

[19] Y. Crozet and J. Coldefy, "Shared Mobility & MaaS, The regulatory challenges of urban mobility," *Journal of ISMAC*, vol. 01, no. 02, 2019.

[20] C. A. Machado, N. P. M. d. S. Hue, F. T. Berssaneti, and J. A. Quintanilha, "An overview of shared mobility," *Sustainability (Switzerland)*, vol. 10, no. 12, pp. 1–21, 2018.

[21] R. Anderson, E. Childs, Y. Doumi, J. Godard, C. Marshall, A. Matthews, K. McConnell, J. Stowe, N. Wallingford, and E. Weisz, "Economic Impact & Operational Efficiency for Bikeshare Systems," Virginia Tech, Alexandria, Tech. Rep., 2014.

[22] "St. Louis Bike Share Study," Great Rivers Greenway District, St. Louis, Tech. Rep., 2014.

[23] Alta Planning and Design, "Redmond, Washington: Bike Share Feasibility Study," City of Redmond, Tech. Rep., 2016.

[24] A. Griswold, "Scooter companies Lime and Bird might have good unit economics," 2018. [Online]. Available: https://qz.com/1325064/scooters-might-actually-have-good-unit-economics/

[25] H. J. Kamps, "How to understand the financial levers in your business," 2018. [Online]. Available: https://techcrunch.com/2018/04/10/how-to-understand-the-financial-levers-in-your-business/

[26] Forbes, "What Drives Value At Electric Scooter Sharing Startups Like Bird?" 2018. [Online]. Available: https://www.forbes.com/sites/greatspeculations/2018/05/01/what-drives-value-at-electric-scooter-sharing-startups-like-bird/#63d4c86667da

[27] A. Griswold, "How long does a scooter last? Less than a month, Louisville data suggests," 2019. [Online]. Available: https://qz.com/1561654/how-long-does-a-scooter-last-less-than-a-month-louisville-data-suggests/

[28] S. Korus, "Electric Scooters: The Unit Economics May Spell Trouble," 2019. [Online]. Available: https://ark-invest.com/research/electric-scooters

[29] L. Caggiani and M. Ottomanelli, "A Dynamic Simulation based Model for Optimal Fleet Repositioning in Bike-sharing Systems," *Procedia - Social and Behavioral Sciences*, vol. 87, pp. 203–210, 2013.

[30] S. Reiss and K. Bogenberger, "GPS-Data Analysis of Munich's Free-Floating Bike Sharing System and Application of an Operator-based Relocation Strategy," *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, vol. October, no. 4, pp. 584–589, 2015.

[31] L. Caggiani, R. Camporeale, M. Ottomanelli, and W. Y. Szeto, "A modeling framework for the dynamic management of free-floating bike-sharing systems," *Transportation Research Part C: Emerging Technologies*, vol. 87, no. April, pp. 159–182, 2018.

[32] B. Legros, "Dynamic repositioning strategy in a bike-sharing system; how to prioritize and how to rebalance a bike station," *European Journal of Operational Research*, vol. 272, no. 2, pp. 740–753, 2019.

[33] T. Bulhões, A. Subramanian, G. Erdoğan, and G. Laporte, "The static bike relocation problem with multiple vehicles and visits," *European Journal of Operational Research*, vol. 264, no. 2, pp. 508–523, 2018.

[34] P. Leclaire and F. Couffin, "Method for Static Rebalancing of a Bike Sharing System," *IFAC-PapersOnLine*, vol. 51, no. 11, pp. 1561–1566, 2018.

[35] T. mobility, "TIER Mobility launches operations with swappable batteries as the first e-scooter provider worldwide," 2019. [Online]. Available: https://www.tier.app/

[36] A. Ajao, "Electric Scooters And Micro-Mobility: Here's Everything You Need To Know," 2019. [Online]. Available: https://www.forbes.com/sites/adeyemiajao/2019/02/01/everything-you-want-to-know-about-scooters-and-micro-mobility/

[37] Wikipedia, "Work breakdown structure." [Online]. Available: https://nl.wikipedia.org/wiki/Work_breakdown_structure

[38] "Historische geharmoniseerde inflatie België – HICP inflatie België." [Online]. Available: https://nl.inflation.eu/inflatiecijfers/belgie/historische-inflatie/hicp-inflatie-belgie.aspx

[39] Publi4u, "Goedkope website laten maken tegen eerlijke prijzen en toch professioneel." [Online]. Available: https://www.publi4u.be/nl/tarieven/

[40] Orange, "Orange IoT Shop." [Online]. Available: https://orange-iotshop.allthingstalk.com/product/nb-iot-intense/?v=d3dcf429c679

[41] Volkswagen, "Bekijk onze promoties op de Crafter Pick-up." [Online]. Available: https://offers.volkswagen-commercial-vehicles.be/nl/bedrijfsvoertuig/crafter-pick-up

[42] Attentia, "Hoeveel betaal je voor het opstarten van een eigen zaak?" [Online]. Available: https://www.attentia.be/nl/faq/hoeveel-betaal-je-voor-het-opstarten-van-een-eigen-zaak

[43] DonkeyRepublic, "The bike fleet - Donkey Republic Bike Owners." [Online]. Available: https://owners.donkey.bike/the-bike-fleet#Principle1

[44] G. Rajkumar and K. Alagarsamy, "A Systematic Review of Cost Estimation Models," *Journal of Global Research in Computer Science*, vol. 4, no. 5, 2013.

[45] Cleveroad, "How to Make an App Like Uber and Estimate Its Cost," 2018. [Online]. Available: https://www.cleveroad.com/blog/estimation-checklist-how-much-does-it-cost-to-develop-an-app-like-uber

[46] Statista, "Proportion of budget allocated to quality assurance and testing as a percentage of IT spend from 2012 to 2019," 2019. [Online]. Available: https://www.statista.com/statistics/500641/worldwide-qa-budget-allocation-as-percent-it-spend/

[47] DonkeyRepublic, "The bike fleet - Donkey Republic Bike Owners." [Online]. Available: https://owners.donkey.bike/the-bike-fleet#Principle1

[48] S. Lekach, "Shared scooters barely last a month, report says. But that could change." 2019. [Online]. Available: https://mashable.com/article/escooter-lifespan-shared-new-models/?europe=true

[49] Alibaba.com, "Zoli Smart Lock Intelligent Qr Code Bicycle." [Online]. Available: https://www.alibaba.com/product-detail/ZOLi-Smart-Lock-Intelligent-QR-Code_60741927785.html?spm=a2700.7724838.2017115.14.2ee02factVsOrT&s=p

[50] ——, "Online Mobile Location Tracking Gps." [Online]. Available: https://www.alibaba.com/product-detail/online-mobile-location-tracking-gps-system_60326145715.html?spm=a2700.galleryofferlist.0.0.338ca78do5TDce&s=p

[51] Logic-immo, "Magazijnen te huur in Oost Vlaanderen." [Online]. Available: https://www.logic-immo.be/nl/huren/magazijn-te-huur/oost-vlaanderen-0,4.html

[52] Allianz, "Premieberekening fietsverzekering voor een gewone fiets." [Online]. Available: https://www.allianz-assistance.be/nl{_}BE/booking/fietsverzekering-prijs-berekenen/gewone-fiets.html

[53] DonkeyRepublic, "The bike-share business - Donkey Republic Bike Owners." [Online]. Available: https://owners.donkey.bike/bike-share-business/

[54] S. Avedian, "The Micro-Mobility Trend, the Economics of it, & the Effect on Rideshare Drivers (Part II)," 2019. [Online]. Available: https://ride.guru/content/newsroom/the-micro-mobility-trend-the-economics-of-it-the-effect-on-rideshare-drivers-part-ii

[55] Alibaba.com, "Powerful 48v 10ah Lithium Ion Battery Pack For Scooter Ebike Frame Battery." [Online]. Available: https://www.alibaba.com/product-detail/Powerful-48v-10ah-lithium-ion-battery_62087853703.html?spm=a2700.galleryofferlist.0.0.3a884545bEijWl

[56] ——, "42v 4a E-scooter E-bike Battery Charger Lithium Battery Charger 36v - Buy." [Online]. Available: https://www.alibaba.com/product-detail/42v-4a-e-scooter-e-bike_62336489599.html?spm=a2700.galleryofferlist.0.0.6cf9bb1aDj5y19&s=p

[57] A. Hawkins, "Skip pulls back the curtain on the high costs of electric scooter maintenance," 2020. [Online]. Available: https://www.theverge.com/2020/1/21/21072785/skip-electric-scooter-life-cycle-maintenance-costs

[58] Consumentenbond, "Wat kost een kilowattuur (kWh) elektriciteit?" 2019. [Online]. Available: https://www.consumentenbond.nl/energie-vergelijken/kwh-prijs

[59] F. Soriguera and E. Jiménez-Meroño, "A continuous approximation model for the optimal design of public bike-sharing systems," *Sustainable Cities and Society*, vol. 52, no. September 2019, 2020.

[60] "The Bikeshare Planning Guide," Institute for Transportation & Development Policy, Tech. Rep., 2018.

[61] L. M. Martinez, L. Caetano, T. Eiró, and F. Cruz, "An Optimisation Algorithm to Establish the Location of Stations of a Mixed Fleet Biking System: An Application to the City of Lisbon," *Procedia - Social and Behavioral Sciences*, vol. 54, no. 1965, pp. 513–524, 2012.

[62] F. Chiariotti, C. Pielli, A. Zanella, and M. Zorzi, "A dynamic approach to rebalancing bike-sharing systems," *Sensors (Switzerland)*, vol. 18, no. 2, pp. 1–22, 2018.

[63] C. Médard de Chardon, G. Caruso, and I. Thomas, "Bike-share rebalancing strategies, patterns, and purpose," *Journal of Transport Geography*, vol. 55, pp. 22–39, 2016.

[64] M. W. P. Savelsbergh and M. Sol, "The General Pickup and Delivery Problem," *Transportation Science*, vol. 29, no. 1, pp. 17–29, 1995.

[65] Google, "Google Maps." [Online]. Available: https://www.google.be/maps

[66] N. Bernaerts, "In 1 jaar 100.000 km gefietst op Cloudbike: nieuw deelfietssysteem kan tevreden terugkijken," 2019. [Online]. Available: https://www.hln.be/in-de-buurt/antwerpen/

[67] W. Vansina, "Vanaf morgen nieuwe deelfietssamenwerking: meer fietsen, hotspots en dropzones," 2020. [Online]. Available: https://www.hln.be/in-de-buurt/mechelen/vanaf-morgen-nieuwe-deelfietssamenwerking-meer-fietsen-hotspots-en-dropzones~ab33f63b/

[68] "Slim naar Antwerpen — Vergunning free-floating deelsystemen," 2018. [Online]. Available: https://www.slimnaarantwerpen.be/nl/mobiliteitsaanbieders/vergunning-free-floating-deelfietsen-en-scooters

[69] P. Lanssens, "Kortrijk en Kuurne lanceren in juni oranje deelfietsen van Donkey Republic," 2020. [Online]. Available: https://www.hln.be/in-de-buurt/kortrijk/kortrijk-en-kuurne-lanceren-in-juni-oranje-deelfietsen-van-donkey-republic~a82166bf/

[70] DonkeyRepublic, "The bike-share business - Donkey Republic Bike Owners." [Online]. Available: https://owners.donkey.bike/bike-share-business/

[71] M. Joris, "Is er nog plaats voor deelfietsen in Antwerpen? Mobit trekt weg uit centrum en verhuist naar het noorden," 2019. [Online]. Available: https://radio2.be/antwerpen/is-er-nog-plaats-voor-deelfietsen-in-antwerpen-mobit-trekt-weg-uit-centrum-en-verhuist

[72] BRUZZ, "Al 12 miljoen ritten op Villo-fietsen," 2018. [Online]. Available: https://www.bruzz.be/mobiliteit/al-12-miljoen-ritten-op-villo-fietsen-2018-06-21

[73] A. Rotty, "Nieuwe speler Circ goed voor 200 extra deelsteps in 't Stad," 2019. [Online]. Available: https://www.nieuwsblad.be/cnt/dmf20190712_04508014

[74] Metro, "Deelsteps Lime legden in een jaar 3,5 miljoen kilometer af in Brussel," 2019. [Online]. Available: https://nl.metrotime.be/2019/11/15/must-read/deelsteps-lime-legden-in-een-jaar-35-miljoen-kilometer-af-in-brussel/