Evaluation of Environmental Effects of Corporate Mobility as a Service

A Case Study

CARL MAY
MSc. Thesis:

“Evaluation of Environmental Effects of Corporate Mobility as a Service”
Case Study

by

Carl May

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Supervisor:
Prof. Dr. Yusak Susilo
Bhavana Vaddadi

Examiner:
Albania Nissan

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Abstract

In times of progressive urbanization and increased environmental awareness, the mobility sector faces the challenge to satisfy an increasing demand, while simultaneously decreasing the negative externalities of transportation. The emerging concept Mobility as a Service (MaaS) claims to resolve this conflict, by offering individualized and seamless mobility through combination of all available modes.

This thesis quantifies the tank to wheel (TTW) greenhouse gas (GHG) emissions of a MaaS implementation and simulates effects of potential variations in the service. The pilot under focus is an alteration of MaaS, which is exclusively available to the work force of a specific corporation. This variation is called Corporate Mobility as a Service (CMaaS). The evaluation is based on cross-sectional survey among the employees and operational data from the CMaaS operator. The transport demand model applies a person category approach.

The total daily GHG emitted by the work force’s on-site mobility is estimated to 3.735 tCO₂. Compared to on-site trips by private cars, trips with CMaaS emit less than half as many GHG emissions per passenger kilometer traveled. This highlights the environmental benefits of MaaS, especially in replacing short trips by private car.

Due to the composition of the underlying data sources and the therefore chosen methodology the reactivity to implemented scenarios is very limited. Thus, analysis and interpretation of the results is restricted to largely aggregated levels.

Nonetheless, this study offers an initial orientation point for further estimation of TTW GHG emissions by MaaS schemes. Beyond, it highlights the lack in understanding and modelling of corporate mobility in general.

Key words: MaaS, CMaaS, corporate mobility, cross-sectional survey, person-category analysis, GHG, societal effects
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1 Introduction

The field of transportation is currently facing several major challenges. On a global level the most prominent one is climate change, which is “extremely likely” to be caused by human activity. The transportation sector plays a key role as it contributes with 14% to the total emissions of greenhouse gases (GHG) in 2010 (IPCC, 2015), while its dependency on fossil fuels, which supplied 95.9% of the final energy use sector in 2016, remains unbroken (IEA, 2019).

On a local level prominent transport related issues are impacts on health due to noise and emissions (Mulley, 2017). According to the European Environment Agency, 39% of the total NO\textsubscript{x} emissions in 2016 were caused by road transport, while 7% of the urban population in the European Union (EU) are exposed to NO\textsubscript{2} levels above the WHO air quality guideline’s threshold (2018). In Germany, violation of air quality standards set by the EU for NO\textsubscript{x} have led to prohibition of diesel cars from affected roads in Hamburg, Darmstadt and Stuttgart (ADAC, 2019).

Beyond this health-related issue, the transportation system is also under pressure with respect to its physical infrastructure, which leads to road congestions and public transport running to capacity. The demand for transportation is steadily growing in urban areas. This is especially the case for Stockholm and Munich. The Swedish population increased by 10.5% from 2008 to 2018 vs. a 18.3% growth in Stockholm county (Statistics Sweden, 2019). Munich’s population increased by 15.4% vs. a national rate of 0.3% from 2006 to 2016 (Ilka Kürbis, 2019). Thus, in an urbanizing world a growing transportation system is competing with residential, commercial and recreational infrastructure for funding, public acceptance and most of all space in an already fully developed urban area.

In order to develop a sustainable urban transport system, the negative effects of the current system, which are mainly related to road transportation by privately owned vehicles, need to be reduced. All strategies – increase in vehicle efficiency, shift to more environmentally friendly modes and reduction of overall demand for transportation – need to be applied. Meanwhile the transportation system needs to fulfill its core mission - providing mobility to the population so that everyone can take part in the necessary and desired activities.
Mobility as a Service (MaaS) is an emerging mobility solution which claims to address these issues in the transportation sector. MaaS bundles multimodal mobility solution into packages. It focuses on the major mobility need of the user, providing on-demand door-to-door transportation. Depending on individual preferences, it presents options for the journey, which vary by mode, time and cost. Further it also enables the reservation and payment of the journey and all this through one interface. (Hietanen, 2014, pp. 2–3). The goal is to provide an alternative to the all-purpose private vehicle, which is dominating the transport system today.

MaaS picks up key societal trends, such as increasing environmental awareness, a general shift towards a more service-oriented society, which is accompanied by the emergence of the ‘sharing economy’. Beyond it is also embedded in technological trends. First and foremost, the digitalization and rise of Information and Communication Technology (ICT), which enables a live communication between user, broker and transport supplier to offer an on-demand service. (Karlsson et al., 2017) Looking more into transport related drivers for the development of MaaS, it is well aligned with the political goals such as minimizing costs for public transport (PT), making the transportation more sustainable and reducing the use of cars. (Pernestål Brenden et al., 2018)

Therefore, MaaS is accompanied by high expectations, which are actively marketed by a lobby forming around the concept. Sochor et al. claims that it could lead to a fundamental change in people’s behavior and is therefore “the biggest paradigm change in transport since affordable cars came into the market” (2016). More specifically, it is associated with higher efficiency in the transport system and thus a reduction in energy use and GHG emissions. It could have positive aspects on health, directly, through more active form of transportation and indirectly, through a reduction of pollutants in urban areas and overall increase the quality of life. (Eckhardt et al., 2017) It could break the dominant culture of private car ownership and decarbonize the transport sector by additionally pushing deployment of electric vehicles (EVs) and other innovations in transportation. It could influence decision making of users and thus further catalyze a more environmentally friendly mobility behavior. (Jittrapirom et al., 2017)

These proclaimed benefits urge for verification through empirical data, which is rare due to a low number of MaaS implementation today. Especially impacts on an societal level have been so far hard to quantify and pilots have at best been able to offer qualitative tendencies. (Karlsson et al., 2017)
MaaS is a challenging concept not only from a technical standpoint but also from an organizational one, as it depends on the cooperation of all actors within transportation with often counteracting objectives. These actors include among others: Regulatory bodies, municipalities, transport authorities, public transport operators, taxi operators, sharing concepts, ICT-services and the user; and even introduces a new actor – the MaaS operator. This high burden for the development of MaaS systems can be lowered by scaling down from this holistic mobility solution to a more specific user case. This effectively limits the number of stakeholders and thus facilitates the development of a MaaS system.

Corporate Mobility as a Service (CMaaS) is such a scaled down concept introduced by Hesselgren et al. whereby the users are exclusively the worker force of a corporation and the service offers transportation within the work site and for commuting. This scope limits the number of stakeholders drastically. The responsibility for the project is clearly placed at the corporation, enabling a more effective or faster development. Additionally, it is easier to attract users, as employees can to a certain degree be forced to sign up to the service. For research, this “sandbox” version offers the opportunity for analyses and to draw conclusion for the general MaaS concept. (Hesselgren et al., 2019)

The MaaS scheme under focus is a CMaaS concept. It has been developed and launched on a 4 km² big company campus in Sweden, which hosts 13,000 employees. From the development of the service in 2017 on over the launch in May 2018 until now, the project has been accompanied by researchers of the KTH own Integrated Transport Research (ITRL). In cooperation with ITRL, this master thesis evaluates the effects of CMaaS on the environment after the first year in full service and feeds back these conclusions to the further development of the given CMaaS system and MaaS in general.

1.1 Thesis Outline

The following chapter Literature provides a deeper insight into the concept MaaS, its evolution and current points of discussion are given. Secondly, this chapter presents research focusing on CMaaS itself, which is mainly evolving around the same case as this thesis. Building on the literature the research objectives are defined. In order to set the table for methodology, the next chapter focuses on the service design and goals of the operators. Also, an overview over available data is given. Methodology clarifies how the thesis
intends to address the research objectives and which models or theories are applied. *Results and Discussion* presents the findings and set them into perspective. Under *Conclusion*, the results and the main take away are summarized. It also features a reflection on the performed research, and points to future research need.
2 Literature

The following chapters will present selective literature from the field of MaaS. The concept of MaaS and CMaaS will be established, critically reviewed and open questions will be addressed, which then guide into the next chapter - Objectives.

2.1 MaaS

Beyond the appeal of MaaS to the user, there are made two general arguments in order to promote MaaS in Public. Firstly, it allegedly fixes existing and well-known problems in the transportation system in an urban context and secondly, it is embedded in general trends in consumption and technology (Pangbourne et al., 2019).

The problems mentioned are centered around the car-dependency of nowadays transportation system in combination with general urbanization. The formerly dominant predict-and-provide mentality, when it comes to handling congestions and urbanization has reached its limitation with respect to space and resources (Mulley, 2017). Congestion weakens the advantages of agglomeration, such as increased accessibility and productivity (Graham, 2007). Consequently, there are new transport solutions needed if cities still want to profit from agglomeration. Additionally, there are several negative externalities of the car-centered transport system such as impact on global warming, air pollution and noise, which have already been addressed in the Introduction. Diverging from the car-dependency could also be achieved by a wider use of existing public transport. According to Kamargianni et al. (2016), main barriers towards an increase usage of public transport are the variety of applied payment methods, tariffs and provision of information by different operators.

Beyond the established problems, there is a general trend towards servicification and collaboration (Pernestål Brenden et al., 2018). In transportation this can be observed in the establishment of sharing offers for cars, bikes and newly also electrical scooters (e.g. Car2Go, DriveNow, MVG-Rad or Tier). These sharing schemes range from private peer-2-peer, free-floating and station based concepts (Eckhardt et al., 2017). Depending on the integration, these services can compete or complement public transportation offers. According to a report by McKinsey, a paradigm shift from car as all-purpose vehicle towards on-demand mobility, which is described as fit-for-
purpose solution, is expected. Shared vehicles could thus account for 10% of sold cars in 2030. (Detlev Mohr et al., 2016).

Secondly, an overall decline in youth licensing is observed in many developed countries, even though the majority among 18 to 30-year-old still hold driver licenses as shown by Delbosc and Currie (2013). In this paper the authors analyzed potential causal factors for the observed decline. The strongest evidence was found for the changes in life stages. Other factors more applicable to the transportation system such as affordability, location, transport infrastructure and attitudes could be linked to the decline in youth licenses but yielded low impact levels. Interestingly, the causal connection between location and transportation, thus accessibility and is directly tackled by MaaS remains unclear. The authors could not determine if decline in driver licensees is the consequence of an increased accessibility or vis versa. But even though the exact reasoning remains somewhat unclear, the fact that youth licensing is declining is a positive trend for the introduction of MaaS.

A third trend, which is often used to promote MaaS is the change in attitudes of the population, especially the growing environmental awareness, e.g. Karlsson et al. (2017) and Pernestål Brenden et al. (2018). In how far this is influencing actual transport related decisions by the users remains a vital point of discussion. The article about the decline in youth licensing found it unlikely, that there is a link between environmentally friendly attitudes and the decline in drivers licenses (Delbosc and Currie, 2013). In how far current movements like Fridays for Future will be able to transfer the environmental awareness to a change in travel attitudes remains to be seen.

Beyond these social trends, the overarching technological trend, is the progress in Information and Communication Technology (ICT) – the 4th industrial revolution (Wong et al., 2017).

2.1.1 Definition and Characteristics

MaaS is a new concept. One significant predecessor, the Mobility Management was firmly established in the early 90s. Its goal was to create a market for matching user preferences to service suppliers and facilitating financial transactions between all stakeholders. Thus, linking together all transportation modes available in an urban context except for privately own vehicles. Mobility Management aimed to be an alternative to car ownership and provide other population groups with better accessibility. (U.S. Department of Transportation, 1991)
More recently, the field of intelligent transport systems (ITS) is identified as breeding ground for the emergence of MaaS (Pangbourne et al., 2019). The term ITS gathers synergetic services such as ticketing systems, sharing services, smartphone applications for real-time travel information and even the development for on-demand transport services for limited sets of modes.

MaaS itself needed key technological milestones especially with respect to ICT to enable a service which provides user centered, holistic on-demand mobility service (Mulley, 2017). A widespread use of smart phones is for example a precondition as it offers the platform to communicate adequately between user and service provider. As already cited above, the first comprehensive definition for MaaS emerged in 2014 by Hietanen. It envisions MaaS to create a co-operative, interconnected ecosystem over the entire transportation sector, effectively dissolving boundaries between different modes.

Since Hietanen, several institutions, stakeholders and researchers came up with definitions and key characteristics, reflecting their perspectives on the concept. The following two definitions present different stakeholders in MaaS.

MAASiFiE is a research project with the goal to develop a European roadmap for MaaS and was launched by the Conference of European Directors of Roads (CEDR) and carried out in cooperation of VTT Technical Research Centre of Finland Ltd., AustriaTech and Chalmers University of Technology. Thus, it leans towards the road authorities and defines MaaS as:

“Multimodal and sustainable mobility services addressing customers’ transport needs by integrating planning and payment on a one-stop-shop principle” (Eckhardt et al., 2017)

The MaaS Alliance on the contrary is a public-private partnership, made up of private companies from the IT, communication and intelligent transport sector and public authorities such as municipalities. Its definition rather represents a technological perspective on MaaS, which is trying to market MaaS as a new business opportunity:

“Mobility as a Service (MaaS) is the integration of various forms of transport services into a single mobility service accessible on demand. To meet a customer’s request, a MaaS operator facilitates a diverse menu of transport options, be they public
transport, ride-, car- or bike-sharing, taxi or car rental/lease, or a combination thereof.” (MaaS Alliance, 2017)

Both definitions evolve around the key characteristics: multimodality, customer-centered and bundling of all mobility services into one service. While the MaaS Alliance stresses the role of the operator, MAASiFiE limits the set of combined mobility services to “sustainable” ones. Instead of coming up with a definition of MaaS others try rather to describe key elements and characteristics of the concept. According to Kamargianni et al. (2016), three key integrations need to be achieved by MaaS. It is worth noting, that these integrations already are well established, but often not combined within one service:

**Ticket and Payment integration**, allowing the user to access all modes through one ticket or device. This integration is already common for PT services within the areas of a transport authority, e.g. Oyster card (London) and SL Access card (Stockholm). For the user this integration facilitates the use of multiple modes due to minimization of barriers between modes for checking and paying. In that way he can take full advantage of the set of integrated modes. For the operator, this also decreases the processing times at stations and busses, which increases the efficiency. Overall, the integration of ticketing and payment leads to a significant increase in demand.

**Mobility package integration**, whereby users can choose between varying pre-paid mobility packages. Through this, marginal travel costs decrease and use of modes included in the package increases, which has also been proven within transport pass ticket literature.

**ICT integration** is the third key element and means the gathering and representation of information from pre-trip to the end of the journey. Thus, it enables journey planning and life-information for the user and on-demand supply management for the operator.

Based on a literature review on existing definitions Jittrapirom et al. (2017) filtered out the core characteristics of Maas: *Integration of transport modes, Tariff options, one platform, multiple actors, use of technology, demand orientation, registration requirement, personalization and customization*. These characteristics can be used to characterize and differentiate between different MaaS systems, providing quick and comprehensive descriptions and facilitating comparisons in general. Additional characteristics, which have been identified in several MaaS definitions and implementations are active decisions influence, inclusion of other services and the promotion as mobility currency. These are not core-
characteristics, but if applicable, can be used for further differentiation between implementations.

In order to describe the interaction between the different actors around MaaS, MAASiFiE develops a MaaS ecosystem defining the roles and responsibilities of the actors. In general, actors can be divided into four different levels (Eckhardt et al., 2017):

- Public and regulatory
- Transport and logistic service providers (i.e. supply side)
- Mobility service (usually acting as MaaS operator)
- End-user

A lot of initial literature is focusing on how to navigate between these stakeholders in order to develop and implement a MaaS system. In CMaaS, the corporation is the only transport service provider and simultaneously acts as MaaS operator. Even the role of public and regulatory level is smaller in a CMaaS scheme, because parts of the mobility service might be rolled out on privately owned land.

### 2.1.2 Development and Implementation

In the early stages of MaaS development the literature mainly focused on defining the concept. While this topic has not been settled universally, it has been adequately addressed and the characterization framework developed by Jittrapirom et al. (2017) has already proven its utility in practice (compare Lindblad and Nygårds (2018)). Another field evolves around the questions, what is needed for MaaS to be implemented and to successfully? (Mulley, 2017) This can be divided into three aspects the technological, system and societal level.

Resulting out of workshops with MaaS stakeholders in Finland, Sweden and Austria within the project MAASiFiE the need for further standardization in ITC for service interfaces and data formats have been expressed. Also, the development and distribution of electronic wallets is identified as a necessity for MaaS. On the system level, the need for qualified leadership, clear assignment of roles and responsibilities within the MaaS ecosystem and the need for adjustment in regulatory frameworks have been expressed. Further, there is also a need for MaaS extensions in current demand modelling, to enable optimization of vehicle fleets and demand-responsive routing (Jittrapirom et al., 2017).
On the societal level, Eckhardt et al. (2017) suggests a further incorporation with policy goals for sustainability, such as reduction in GHG emissions, energy use, public health and quality of life. In this context, MaaS also needs to offer solutions for equity issues, especially concerning inclusion of elderly people and more rural areas.

### 2.2 Expected Benefits of MaaS

As already indicated in previous chapters MaaS is connected to high expected benefits. In the following paragraphs, these expectations and promises will be summarized in a more structured manner, by categorizing them according to their main beneficiary.

**User**

The main promise made by MaaS to the user is *freedom* in choosing on-demand transportation, by offering multitude of mode combinations, tailored to the customers’ needs and preferences (Pangbourne et al., 2019). Being an alternative to the *all-purpose* vehicle, it frees the customer from the sunk cost and consequential impacts on mode choice of a car-ownership and enables the user to make the ideal choice for the given trip. The second major promise is to save time in transportation through ideal combination of the integrated modes and reduction in parking time. For non-car-owners it increases the accessibility and the reliability of the mobility service.

On a secondary level it appeals to the user by its potential positive effects. Through the implementation of active modes (walking and cycling) it can contribute to the health and well-being of the user as physical activity has been proven to improve life expectancy, stress tolerance and decrease the risk for several diseases including type-II-diabetes, obesity and cardiovascular ones (Nicolopoulou-Stamati et al., 2005). In case the user wants to reduce his environmental impact through transportation, certain MaaS schemes promise to achieve this without cutting back on mobility. It enables the user to express his environmentally friendly attitude in actual decision.

**Policy Maker**

The central promise made to policy makers especially in urban areas is an increase in *efficiency* through better utilisation of existing resources and reduction of congestion (Pangbourne et al., 2019). Better information on
actual demand and supply through the digital processing can positively affect the reliability and improve the indication of shortcomings in the transport system, leading to more efficient allocation of recourses in real-time and in planning. GHG-emissions and air pollution are supposed to be reduced through the promotion of more environmentally friendly modes as PT and biking, fulfilling environmental policy goals with respect to mitigation of global warming and public health. The latter is thus tackled on two levels, by reduction of air pollution and increase in active travel modes as described above. Through the potential reduction of private car ownership, MaaS could free public space currently reserved for parking for other urban development (Wong et al., 2017) and thus create value through increased quality of life for the citizens and/or real-estate development. The increased accessibility for non-car owners amounts on an urban scale to an increase in real estate value and on a societal scale to an improvement of equity.

It can also improve the image of a city by highlighting the application of smart technology in transport management and ticketing. This motivation is especially prominent in Netherland and Belgium (Pangbourne et al., 2019). Additionally, MaaS could offer a faster trajectory to the widespread implementation of new transport technology as electric or even autonomous vehicles (EVs and AVs) and thereby help to decarbonize the transport sector (Jittrapirom et al., 2017).

2.3 Critical Review

The expectations towards MaaS are overwhelmingly positive, portraying the socio-technical innovation as logical trajectory from the current transport
system to a more sustainable future one. This vision is challenged on several levels. Pangbourne et al. (2019) criticizes the concept itself and challenges causalities in the argumentation for MaaS. Firstly, the authors point out the discrepancy between the promise to offer on-demand door-to-door solution for any desired trip, and the limited capacity of the transport network. Under the current transport situation, with negatively perceived externalities like congestion, air-pollution and GHG-emissions, such a promise is deemed unfulfillable and deceptive by the authors.

Secondly, the authors discuss the problematics arising from a potential regime status of MaaS in a geographical area. Such a monopoly poses threats like big data accumulation and the disruptive economic developments associated with monopolies. It also poses the threat of technological uniformity, ignoring the complexity of transportation. Lastly, the authors also highlight the implications on social equity, excluding people who cannot afford the service from mobility. Lindblad and Nygård (2018) also extend this issue to the context of urban vs. rural areas, as current MaaS developments focus on urban areas with already good developed PT offers.

Pangbourne et al. does not conclude to abolish MaaS as a concept, but rather aims to raise awareness for the bias promotion deployed by many MaaS actors. Secondly, the authors point out the need for policy intervention, to ensure that MaaS contributes to a more sustainable transport system in an urban context. This is a common theme across MaaS (Mulley, 2017). This points towards a major gap in MaaS literature the lack of empirical prove for environmental, economic, and social impacts of MaaS to back up the expectations build up around the innovation. More specifically, this addresses the need for comparable impact assessment for MaaS (Eckhardt et al., 2017).

Due to limited number of pilots and actual implementation, there is a lack of available data for quantitative analysis. For instance, even though the private MaaS operator Whim launched his service respectively in 2016 (Helsinki, Finland), in 2017 (West Midlands, United Kingdom) and in 2018 (Antwerp, Belgium) data on actual usage is hard to find. In the Deliverable 4: Impact Assessment of MaaS, MAASiFiE summarizes the results of the MaaS pilots UbiGo (Gothenburg, SE) and SMILE (Vienna, AT) and MaaS-related car and bike sharing services. The available data only allowed qualitative assessment of impacts. The effect of the pilots on the KPIs for societal level (emissions, resources efficiency, composition of vehicle fleet and citizens’ accessibility to mobility transport services) is only specified as increase or decrease, translated to a positive or negative effect on the
respective impact category. Based on the pilots under investigation it concluded, that societal level impacts for economy and society are positive, while impact on environment is positive with respect to emissions, but positive and negative with respect to the modification of the car fleet. (Karlsson et al., 2017)

Pangbourne et al. (2019) questions the argumentation how MaaS is contributing to more sustainable transportation. While the reduction of private car ownership contesting the current car dominance is acknowledged, the authors focus on the reason for this reduction. If this is achieved through an enhanced access to non-car or shared vehicle modes, this can have a positive effect on emissions and congestion. But if private car trips are replaced by taxi trips, the overall VKT remain on the same level and thus undercutting the claim, that MaaS reduces emissions and congestion. Additionally, the paper points out, that VKT could even be increased by MaaS through two mechanisms. The pre-paid packaging of mobility offers including unlimited options, could lead to an upsurge in the usage of these modes (compare theory of loss aversion (Tversky and Kahneman, 1991)), increasing the passenger kilometer traveled (PKT), with uncertain effects on overall VKT. Additionally, there is evidence that ride-hailing, attracts users away from PT, due to its convenience (Clewlow and Mishra, 2017). Especially if MaaS includes large free-floating carsharing offers, it resembles a door-to-door service and could thus have the same effect.

2.4 CMaaS

An unexplored variation of MaaS is CMaaS. Corporate mobility is by no means a totally new concept as other companies are also offering commuting and on-site trip solutions to their employees, but as pointed out by Lindblad and Nygårds (2018) it has rarely been academically addressed. Therefore, the literature presented in the following paragraphs is mainly evolving around the same case. In the beginning, the focus was on optimizing the development and design of the CMaaS by identifying potential barriers through investigating user practices (Hesselgren et al., 2019) and investigating the business model of CMaaS (Lindblad and Nygårds, 2018). A third study focused on user attitudes and expectations towards MaaS and potential shifts in car-ownership and mode-choice (Varela et al., 2018) and thus already analyzed potential effects of CMaaS on the user.

In the paper Understanding user practices in mobility service systems: Results from studying large scale Corporate MaaS in practice,
published 2019 in Travel Behaviour and Society, Hesselgren et al. present there results of their research on the given case. Through a service design approach, user mobility practices, travel needs and drivers for such were investigated. The research accompanied the development and the initial uptake of the CMaaS system through four rounds of user interviews from October 2017 to June 2018. The focus was set on internal transportation. The three main barriers for adoption of CMaaS identified through this approach are:

- Lack of integration with external transportation, such as public transport (PT)
- Corporate culture, which encourages physical meetings
- Regulative system limitations by law or the company policy

These barriers will be used to discuss the results of this thesis as they give indications for potential feedbacks into the design of CMaaS and MaaS in general. The unchallengeable corporate culture of encouraging physical meetings sets a limit to the potential reduction in on-road transportation for the given CMaaS, as it is not aiming to reduce the travel demand itself.

One goal of researchers and operators alike is to develop potential business scenarios for CMaaS. Through a business model perspective, the master thesis Corporate Mobility as a Valuable Service? by Lindblad and Nygård (2018) explores CMaaS by investigating what value can be created and captured and how risks and revenues are allocation among the actors. In this case the actors where the company with the given CMaaS, a potential buyer of the service – Company X – and the employees of Company X. Based on the conducted interviews with the actors different perceived values have been identified and where categorized into financial, social and environmental. With respect to financial values the reduction of time waste was dominant for all three actors. Interestingly, the social values are centered around the benefits and wellbeing of the employees for all actors. With respect to the perceived environmental value, the corporations highlighted the reduction of CO2 emissions, while the employees of company X appreciated more general the environmentally friendly transport. In how far the service achieves the reduction in CO2 emissions has not been addressed by the study but was left open for future research.

The article User attitudes towards a Corporate Mobility as a Service by Varela et al. from 2018 investigate user attitudes of the given CMaaS, by establishing two latent user classes: Car-oriented and shared-mobility oriented. The base for the analysis was the first user survey from April to
June 2018, socio-demographic characteristics, mobility-related attitudes and normative beliefs towards the use of different modes of transport. Through this approach 75% of the respondents were allocated to the car-oriented class. Usage of car for internal travel within this class was found to be higher, whereas the shared-oriented class features a higher usage of non-motorized modes for internal travel. The affiliation of a respondent to one of the classes was determined by socio-demographic characteristics, mobility-related attitudes and normative beliefs towards the use of different modes of transport. Among these, gender, blue- or white-collar worker and living location could not be linked to a class membership. Higher management level and the presence of children on the other hand increased the likelihood to be car oriented. Younger people between 18 and 24 on the other hand were more likely to fall into the shared mobility-oriented class.

2.5 Open Questions around MaaS

On a conceptual level, MaaS has been studied and promoted excessively. The needs for implementations towards actors, technology and mobility providers have been defined in a multitude of roadmaps. The alleged positive effects however have rarely been proven but are at the same time often benevolently adopted as MaaS fits perfect into current societal trends. Also, there is a great risk that benefits are one-sided positioned on the individual level, risking to further increase negative externalities of transportation on a societal level.
3 Objectives

The aim of this master thesis is to contribute to the ongoing discussion and development of MaaS by offering empirical insights into a fully functional CMaaS service. This is especially needed on a societal level, which will be the focus of this evaluation. The second objective is to identify and quantify untapped potentials to increase positive and decrease negative effects of the given CMaaS and transfer these findings to MaaS in general. In order to achieve these overarching goals, different using groups and/or patterns need to be identified through the survey and projected to the overall corporate mobility. Based on that estimation the current mobility regime under CMaaS can be evaluated and potentials for improvement can be demonstrated. Through this process understanding of relations between design and effects of the given CMaaS can be studied, which eventually provides feedback to the concept CMaaS and eventually MaaS itself.

The case under review only qualifies as MaaS system within the worksite, as it does only offer one solution for commuting. Therefore, the scope of the analysis is limited to internal transportation on-sit. Due to the public prominence of the topic global warming, the personal interest and knowledge of the researcher and time constraints the evaluated societal impacts are reduced to estimation of the tank to wheels GHG emissions, caused by the corporate activity.
4 Case

The CMaasS under review is developed for and with the company with 13,000 employees in a collaboration with a software supplier for Intelligent Transport Systems, the local public transport authority and several KTH entities such as ITRL, Integrated Product Development and Industrial Economy (Integrated Transport Research Lab, 2019). The following chapter will state the objectives and gives a short overview over the service design and development of the CMaaS scheme.

4.1 Situation and Objectives

The site lies 30km south of Stockholm, Sweden. The 4 km² big site hosts 13,000 workers and the longest distance between buildings is 5.2 km. 32% of employees are in the adjacent town while the remaining 68% are mainly recruited from Stockholm and its surrounding suburbs. The site offers 7,700 parking spots and in 2015 69% of the employees commuted by car. The current corporate mobility which is mainly based on utilization of private car for commuting and on-site trips during the workday, has long reached its capacity, leading to congestion on-site during rush hours and long parking search for work related on-site trips. Beyond it is obviously discriminating against employees, who do not have access to a private car and is therefore no longer practical nor sustainable. (Lindblad and Nygårds, 2018) Secondly, parking spots are blocking valuable real estate, which could otherwise be used for further development of the factory site. On a business level, it is also crucial for the company to attract young, highly qualified people from Stockholm, which is home to two universities and several other research institutes. The company acknowledges the decline in driver licenses among this demographic, and thus the need to offer a sustainable corporate mobility solution in order to stay relevant as an employer. Additionally, in developing such a corporate mobility solution, the company also identified a new business opportunity, for further application in cities or other corporations.

The CMaaS scheme under review has been in initiated in 2017 and was developed out of the beforehand existing mobility offers for employees namely the commuter bus service to central points in Stockholm and a shuttle service on-site, which operates minibuses on 3 routes, targeting on site trips. Additionally, a station-based E-Bike sharing service and a Taxi service has been introduced. All these services are bundled on one digital platform (CMaaS App), which enables planning, live tracking, booking and
ticketing of the trips. The system is managed by an internal department of the company. The company itself formulated four central objectives towards the service:

- Providing cost-efficient mobility for employees
- Focus on customers’ satisfaction
- Delivering a synchronized transport solution for the users
- Supply sustainable transport on the long-term

Additional goals of the project are lowering the congestion on and around campus, especially with respect to limited parking space. Offering alternative mobility options to a changing demographic, with decreasing car access and thus staying an attractive employer with high accessibility. And lastly, developing and testing a new business model, which could be sold to other companies or municipalities.

An indicator framework serves to transfer the abstract goal of sustainable transportation into well-defined effects and associated measurable key performance indicators (KPI). Through the formulation of an indicator framework, the development and evaluation of a project are controlled and a lasting trend towards sustainable transport evoked (Litman, 2007). Within the project such indicator framework has been developed and applied. The effects and corresponding KPIs developed for this framework are allocated to three levels:

- Individual - effects on the user
- Organizational – performance of the provider
- Societal – impact on the society as a whole

Within these levels, the effects are categorized by environmental, economic, and social. An overview on effects and corresponding KPIs is given in Annex 1.

4.2 Design

The formerly introduced key integrations of for MaaS established by Kamargianni et al. (2016) are used to characterize the given CMaaS scheme in Figure 1. The integration of mobility packages bundling different modes into packages or offers establishing a multi modal travel budget has not been realized within the given scheme. This is mainly due to the fact that the on-site mobility options are free of charge. To display the multimodal
As shown through Figure 1 the ICT-integration is kept as simple as possible for the user and operator. For the user, the app focuses on the visual depiction of arrival and departure times for Shuttle and Commuter Busses. This is achieved in form of timetables and live tracking of vehicles on a campus map including the user’s location. For the Taxi service the app only lays out the basic information on how to book the service through the operator and for EBike it shows the live availability of bicycles at the station. Additionally, the app enables the personalization through favorite destinations and access to meeting locations through an interface to the company’s organizer program. The app also enables notifications by the operator to the users about changes in schedules or the availability of the service.

For the operator the ICT-integration mainly helps the dispatcher to keep an overview over the current situation by offering a live tracking of all vehicles (Shuttle and Taxi), which also depicts delays. Through a tablet in each vehicle, the dispatcher can directly communicate and thus react to unpredicted traffic situations. The central dispatcher is also responsible for

Figure 1: Realization of key-integrations within given CMaaS.
the operation of the Taxi service. A transport by Taxi is ordered by the user through phone the latest 15 minutes before departure. The dispatcher receives the call and performs the routing of the Taxi vehicles manually. Once again, the interface to the drivers are used to communicate the pick-up and drop-off location and time.

The integration of ticketing and payment is only in so far applicable to the given CMaaS scheme as only the commuter service requires payment by the customer. This can be done via the app and tickets can be uploaded to the app. Shuttle and EBike are completely free of charge. The Taxi service on the other hand is only available to people who need to travel to or from a location which is not covered by the Shuttle service. The costs are covered by the user’s department within the company. Thus, the journey needs to be related to his duties. The usage of the Shuttle and EBike service are free from such a purpose.

Figure 2 shows a schematic map of the CMaaS services and the campus. As this thesis focuses on the on-site travel behavior, only the modes which are available for on-site trips are represented. Links to commuter services the CMaaS Commuter Busses or public transport are also dropped from this representation. The 13,000 employees are spread over the 14 working areas indicated in the map (A-N). The Shuttle service is operating its 14 minibuses on 4 lines, connecting 19 Shuttle stops. All lines have their starting point in area A. The EBike sharing service is a station-based operation with 40 available bicycles. An EBike can be used up to 30 minutes and needs to be returned to one of the 4 indicated stations located at the areas A, B, E and K.
Figure 2: Schematic map of CMaaS (own representation with ArcGis Desktop 10.6.1 (ESRI, 2018))
5 Data

For this thesis, three different sets of data all provided by the corporation are used. Firstly, the results of three surveys among employees about the use and satisfaction with CMaaS, including socio-demographic information. Secondly, socio-demographic information about all the employees on-site and thirdly, operational data from the service itself such as, car mileage, consumptions, and users. The following three paragraphs present the available information, explains processing of existing and computing of derived variables within the data and highlight crucial points about the variables’ characteristics and relation between the surveys. The following Table 1 illustrates the period of time in which the respective data sets have been collected.

<table>
<thead>
<tr>
<th>Year</th>
<th>2018</th>
<th>2019</th>
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<td>Employee data</td>
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<tr>
<td>Operational Data CMaaS</td>
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<td>Taxi</td>
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<tr>
<td>Shuttle</td>
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<td>EBike</td>
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5.1 Surveys – Available Information

The survey under focus is the last of three cross-sectional survey carried out within the project. It was not specifically designed for this thesis. Annex 2 provides an overview over the questions in survey 3, highlights the availability of similar data in survey 1 and 2 and describes the carried-out transformations to obtain a workable data file. When referring to question numbers in the following like ‘Q1’, it refers to the question number provided in survey 3, unless specifically stated otherwise.
Survey 3 is composed of 44 questions, while several also include sub questions or allow multiple response questions. In total, the responses result in a set of 96 variables. The provided information can be divided into three broader categories, which are presented in the following:

5.1.1 Socio-Demographics (Q1-3, Q35-44)

This part can further be divided into questions about the respondent’s household (Q1–3) and information about the respondent himself (Q35-44). With respect to the household, the number of persons, children and age of children are specified. Generic information about the respondent include gender, age, domicile specified by postal code and municipality and information about the position within the company, such as manager level, company department on 3 levels and the distinction in blue- or white-collar worker.

5.1.2 Mobility Behavior (Q4-13)

Once again, these questions can be divided into subcategories. General mobility preconditions are addressed through Q4-6, clarifying the availability of a bicycle, car and driver’s license, as well as the primary working location and the average amount of days per week spent on-site. Secondly, travel practices such as mode choices and travel frequencies are stated by the user in Q8-13. In Q13, respondents state number of multimodal trips (commuting and on-site) per day. It is worth noting, that the questionnaire asks for ‘typical’ values, representing their normal corporate travel practices. Also, values refer to two different time scales ‘per week’ and ‘per day’, which must therefore always be clarified.

For commuting, the respondents state if they use the respective transport mode. The multiple response set of available alternatives is compiled of the CMaaS services commuter buses, Taxi, Shuttle busses and EBike, and the regular transport modes PT, walking, cycling, personal car as driver and personal car as a passenger. It also includes the possibility to state a non-listed mode, but as explained under Annex 2, these answers are transformed into the given set of alternatives, when applicable.

For on-site trips, the option commuter buses are not available, but the option car sharing, also including the use of department cars, is added. Beyond, respondents also state the number of trips per day and time spent for traveling per week. Additionally, respondents also list on-site
destinations through a multiple response set of 13 available options covering the entire campus and the additional option of stating other destinations.

5.1.3 Experience and Satisfaction with CMaaS on-site (Q15-34)

This part of the questionnaire firstly focuses on the experience and satisfaction with the CMaaS entities Shuttle, Taxi and EBike individually (Q15-27) and secondly with the service overall (Q29-34). The questions mainly target the on-site mobility of the respondents. In case of the individual services only the respondents, which identify as users are asked follow-up questions. The part about CMaaS is divided into follow-up questions for non-users and users. Responses, which correspond to a statement made in the questionnaire are recorded on the 5 level Likert scale.

For the individual services, assessment of access or waiting times are given. Average in vehicle travel time for Shuttle and Taxi are also stated. For all three services, the satisfaction with pre-trip and real time information access is recorded. Additionally, the users of Shuttle also rate the punctuality of the service.

Non-users of CMaaS are asked for reasons why they do not use the service in closed questions, targeting issues which are hypothesized to motivate non-use by the researching team based on former studies and communications with operators. These issues include scheduling, geographical coverage, the nonexistent need for mobility on-site and dissatisfaction with the app and the service in general. CMaaS users are asked for their motivation to use the service specifically targeting the themes curiosity, comfort, flexibility, efficiency, economy, environment, trip planning, reduction of car usage and parking search. Users are also asked in how far they agree that CMaaS has reduced their private car usage and that CMaaS made on-site trips easier. Finally, the overall satisfaction with the service is rated on the Likert scale. Both, the section targeting motivations for non-use and use also include one open question for respective reasons.

5.2 Employee Data

The data set was provided by corporation and dates to September 24th, 2019. It includes socio-demographical information on all employees on-site. It provides information on gender, age and domicile, as well as work related information as building within the campus, blue- or white-collar,
management level and division. This information is identical to survey 3 Q35-44 and is thus treated in a similar way with respect to data processing.

5.3 Operational Data CMaaS

The operational data is also provided by the corporation, which is acting as operator of the transport service. It is also analyzed within IBM SPSS. It offers differing sets of data for the three CMaaS entities Shuttle, Taxi and EBike and provides information on the used vehicle fleet. The presented data is considered complete for the range from June 2018 to August 2019. All data provided is on a monthly basis. For all three services the number of monthly customers and vehicle kilometer traveled (VKT) is given. For Shuttle and Taxi, the days in service per month and the gas consumption is provided. There is no information on occupancy or capacity of the services.
6 Methodology

Within this thesis the singular considered externality are the direct GHG emissions (CO$_{2eq}$) caused by the corporate mobility on site. These tank to wheels (TTW) GHG emissions ($E_{CO2}$) are calculated by multiplying emission factors ($EF_{CO2}$) with the respective activity ($A$) data for each mode ($k$) as shown in equation (1). This process is comparable to an activity-based emission inventory.

$$E_{CO2} = \sum_k EF_{CO2}^k * A^k$$ (1)

The development of the mobility model is heavily driven by the availability of data and focuses on the correct estimation of the mobility behavior of the population. Because there is no detailed information on further traffic situations as average speeds, traffic flow or density around the site, the activity is simplified to vehicle kilometer traveled (VKT) or passenger distance traveled (PKT) depending on the mode. As pointed out under literature, corporate mobility has rarely been addressed in academic research. Additionally, MaaS has so far not been consistently included into transportation modelling (Jittrapirom et al., 2017). Thus, the modeling of a CMaaS is unestablished on several levels. Therefore, the sub sequential estimation of the overall travel demand of the corporate mobility is based on an excessive analysis of the available information on users expressed in survey 3 and operational data of the CMaaS scheme under review. Survey 3 constitutes a cross-section of the population and their revealed mobility behavior at a single point in time. The estimation follows the linear structure of classic transport modeling consisting of trip generation, distribution, modal split and assignment.

6.1 Definitions and Notations

Basic definitions, notations and criterions for the general zoning and network system are drawn from Ortúzar and Willumsen (2011) and are as follows.

- **Trip:** All one-way movements by employees from one point within the campus to another. Changing from one building to
another is the threshold to establish a trip. All trips are work-based (analogous to home-based in regular modelling), as there is no information on other origins. Trip chains are not captured by the survey. Trips are represented in a two-dimensional array \( \{ T_{ij} \} \), the trip matrix. \( T_{ij} \) donates the total number of trips from origin-zone \( i \) to destination-zone \( j \). All trips originating in zone \( i \) are donated by \( O_i \) and all trips attracted to zone \( j \) by \( D_j \).

- **Trip Production:** The origin of a trip, equal to the employees working locations as there are no other trips recorded in survey 3.
- **Trip Attraction:** The destination of a trip.
- **Trip Generation:** Total number of trips generated by employees of a zone.
- **Trip Rate \( (t) \):** Number of trips made during a working day by an average person.
- **Mode:** All modes available for on-site trips. The disintegration of the trip matrix into modes is indicated by a \( k \): \( T_{ij}^k \).
- **Zoning design:** The study only includes on-site trips within the study area, which consists of the 14 working locations (A-N) established under chapter 4 Case. According to the corporation the working areas can somewhat be considered homogeneous in their respective land use. These 14 working locations are used as ‘Destinations’ within survey 3 and both, the respondents to the survey and all employees can be assigned to one definite working location. Thus, these 14 working locations are established as Traffic Assignment Zones (TAZ).
- **Network Representation:** The network is represented by direct unidirectional links between centroids of all zones. This large simplification is made, due to several reasons:
  - Missing information of traffic loads on campus, as it is part of the regular road network and internal traffic is a minor contributor to congestion.
  - The sole purpose of the calculation is to estimate the PKT. Therefore, only the traveled distance per trip is of interest. Checking with maps of the campus, this is sufficiently estimated by direct links between the zones.
6.2 Estimation of GHG Emissions

The flow chart in Figure 3 describes the general methodology used to estimate the GHG emissions. The right column depicts the general steps of the estimation with their respective intermediate results passed on to the next step. The left column indicates the underlying sources used within this step, while the column in the middle shows how this data has been transformed to supply the general steps in the necessary form. Trips are aggregated on the level of zones, while $i$ is indicating the origin and $j$ the destination zone.

Figure 3: Flow chart of estimation of GHG emissions.
Underlying assumptions and explanations are given in the following under the corresponding subchapter, marked with asterisk.

A: Trip Rate to Destinations

The only information available through survey 3 on the sample’s trip generation and distribution are the revealed trip rate (Q9: How many trips on-site do you make during a regular day?), the information on the respondents working location (Q5) and a set of common on-site destinations (Q10: To which destinations do you travel during a regular day?). There is no information on alternative trip production, differing from the respondents working location, on possible trip chains nor on activities at the destination which are would be the purpose for the trip.

Under this situation with limited information an approach similar to a person category analysis as described by Ortúzar and Willumsen (2011) is chosen to estimate the trip generation and distribution. Applying this method to the given study, the average number of trips with specific purpose is estimated as a function of person attributes. Because the purpose of trips is not revealed through survey 3, purpose is replaced by directly estimating the number of trips to destination \( d \) per person of type \( h \). The trip rate \( t^j(h) \) is then the observed trips \( T^j(h) \) by destination divided by observed number of respondents of this person type \( N(h) \):

\[
t^j(h) = \frac{T^j(h)}{N(h)}
\]  

The choosing of these attributes, stratifying the respondents and employees into categories is explained under 6.2.1 Selection of Category Variables. In the following the calculation of observed trips \( T^j(h) \) based on the responses to survey 3 is explained:

As mentioned above, the respondent \( n \) reveals his on-site trip rate per day \( t(n) \) through Q9 and additionally, the number of days on site per week \( d(n) \in \{1 \, \text{day}; \ldots, 5 \, \text{days}\} \) through Q6. Destinations are specified through Q10, which reveals a set of common on-site destinations by respondent \( D(n, j) \). \( D(n, j) = 1 \), if respondent \( n \) listed destination \( j \) as common on-site destination and \( D(n, j) = 0 \), if he did not. Since there is no further information on differing trip rates within the set of destinations it is assumed
that the number of each respondent’s trips are equally distributed over the set of revealed destinations. Thus, the respondent’s number of average daily trips to a specific destination $T^j(n)$ is calculated as follows:

$$T^j(n) = \begin{cases} 
\text{Missing; if } t(n) = \text{Missing } \lor d(n) = \text{Missing} \\
0; \text{if } \sum_j D_j(n) = 0 \\
t(n) \cdot \frac{d(n)}{5 \text{ days}} \cdot \frac{D(n,j)}{\sum_j D(n,j)}; \text{else}
\end{cases} \quad (3)$$

The observed trips by destination $T^j(h_1)$ used in equation (2) is the number of trips by respondents aggregated over person type $h_1$. The resulting trip rate to destination by person type $t^j(h_1)$ is passed on to Trip Generation and Distribution.

**B: Employees per Zone**

The number of employees per zone $N_i$ are derived from the employee data set, which indicates the primary working location on site through the building name. These building names are allocated to one unique zone. The distribution of the person types among all employees per zone $\alpha_i(h_1)$ is carried out according to the attributes, which have been found to cause significant differences in trip rates and destination choice.

**C: Trip Generation and Distribution**

Using the results of the two preliminary steps, the trip matrix is calculated by aggregating the trip numbers over the set of all defined person types $h_1 \in H_1$:

$$T_{ij} = N_i \sum_{h_1 \in H_1} \alpha_i(h_1) * t_j(h_1) \quad (4)$$

Utilizing the available information, this procedure leads to singly constrained trip matrix as only the trip production rate is utilized. Even though the trip matrix could be balanced through further procedures, this
would on one hand minimize the information in the estimation, as the motivation for each trip, the on-site destination is further distorted. On the other hand, this would not improve the results of the estimation as it only focuses on the VKT, which are already accounted for because the respondents revealed the total number of daily trips in their responses to Q9 and thus also included the return trip from the destination in that count. Thus, the production constrained trip matrix $T_{ij}$ is passed on to Modal Split.

**D: Mode Share per Zone**

Unfortunately, the revealed set of used on-site modes (Q11: Which transport mode do you usually use for on-site trips?) is not linked to a specific on-site destination in survey 3. Thus, mode shares are calculated at the trip production, disregarding the destination. To estimate the mode share per zone, an approach like the person category analysis is chosen. The mode share or the proportion of trips $p$ traveling by a certain mode $k$, is calculated by analyzing a certain type of persons $h_2$, who revealed similar behavior, with respect to mode choice. This person type uses a different categorization than the person types utilized within Trip Generation and Distribution. Thus, the proportion of a specific mode among the set of all available modes $K$ for a type of person $h_2$ is calculated by dividing the number of trips with mode $k$, $P^k(h_2)$ by the number of trips with all modes combined among this person type:

$$p^k(h_2) = \frac{P^k(h_2)}{\sum_{k \in K} P^k(h_2)}$$

Once more, the number of trips per mode is not directly revealed by the respondents to survey 3, but needs to be estimated using each respondents on-site trip rate $t(n)$, his number of days on-site per week $d(n)$ and Q11: Which transport mode do you usually use for on-site trips?, which reveals the set of on-site modes each respondent uses $M(n,k)$. $M(n,k) = 1$, if respondent $n$ listed mode $k$ as common on-site mode and $M(n,k) = 0$, if he did not. Since there is no further information on differences in usage within the set of listed modes it is assumed that the number of each respondent’s trips are equally distributed over the set of revealed on-site modes. Thus, the respondent’s number of average daily trips with a specific mode $P^k(n)$ is calculated as follows:
The total number of trips per mode and person type $P^k(h_2)$ used in equation (5) is the number of trips per mode per person $P^k(n)$ aggregated over person type $h_2$. Secondly, the mode share needs to be aggregated over all occurring person types $h_2 \in H_2$ on the zonal level utilizing the share of the specific person type within all employees of each zone $\beta_i(h_2)$:

$$p^k_i = \sum_{h_2 \in H_2} \beta_i(h_2) * p^k(h_2)$$

The resulting mode share per zone $p^k_i$ is passed on to Modal Split.

The assumption that the mode share of a certain category of persons is adequately estimated by equally distributing the set of modes per person over its daily trips (equation (6)) and subsequently aggregating all trips over the category (equation (5)), is validated based on the responses to survey 2: Since respondents to survey 2 revealed all information necessary to calculate the mode share through the procedure. Additionally, the respondents directly reveal the number of trips per mode. This comparison is carried out under Validation of Mode Share Estimation. Even though, survey 2 provides no information on destination choice, the methodology used to estimate the trip rate to a destination under A: Trip Rate to Destinations is also validated by this comparison, because it uses the same methodology.

E: Modal Split

The sum of all trips from $i$ to $j$ by mode $k$ are directly calculated by multiplying the entry of the trip matrix $T$ by the production-based mode share:

$$T^k_{ij} = T_{ij} * p^k_i$$
\( T^k_{ij} \) is passed on to Validation/Correction.

**F: Target Values CMaaS Trips**

Based on the, through the CMaaS operator reported customer numbers per month and the days in service per month, daily customer numbers for CMaaS entities Shuttle, Taxi and EBike are derived. Customer numbers translate directly into total number of trips by the respective mode. Since, these values are used for validation and correction of the estimated trip matrix, it is important that these target values represent a ‘regular’ day with respect to on-site mobility, thus excluding values which represent outliers. As the Shuttle service features the highest customer numbers, target values for average daily Shuttle usage \( T^\text{Shuttle} \) are considered to be more robust than the ones for Taxi and EBike and is thus the primary target value.

**G: Validation/Correction**

The only option for empirical validation of the estimation process is the comparison of the estimated total number of trips per CMaaS entity (e.g. Shuttle in equation (9)) to the from the operator reported trips per mode \( T^r \).

\[
T^\text{Shuttle} = \sum_i \sum_j T^\text{Shuttle}_{ij}
\]  

(9)

In case the estimated value \( T^\text{Shuttle} \) is in the same range as the reported value \( T^r_{\text{Shuttle}} \), the secondary target values for Taxi and EBike are revisited, to further check upon the correctness of the estimation. If positive, then the estimated trip matrix by mode is passed on to Assignment.

In case the estimated values differ significantly from the reported target value \( T^r_{\text{Shuttle}} \), this is either indicating shortcomings in the methodological approach or flaws of the underlying sample of the estimation, which needs to be addressed in the discussion. To proceed with a correct trip matrix for each mode, the original trip matrix is corrected to fit the target values, because due to the direct reporting of the customer numbers through the operator, these trip numbers are considered to be significantly more reliable than the
estimated values. The correction factor $CF$ is calculated according to equation (10) and is applied on all entries of the trip matrix after Trip Generation and Distribution.

$$CF = \frac{T_{Shuttle}}{T_{Shuttle}}$$

Modal Split remains unchanged and the corrected trip matrix by mode is passed on to Assignment.

**H: Assignment**

As alluded to under 6.1 Definitions and Notations detailed modelling of the network for each mode is out of scope for this study. Instead of modelling the traffic situation around the campus, this thesis sole aim is to estimate GHG emissions. Thus, the only relevant information from this step are the VKT or PKT, depending on the mode. The network is therefore independent of mode and reduced to direct bidirectional links between the centroids of each zone, indicating the trip length for each trip from zone $i$ to zone $j$ for $i \neq j$ by the array $\{D_{ij}\}$. The length of internal trips within one zone is estimated based on the area $A_i$ of each zone.

$$D_{ii} = \frac{1}{2} \sqrt{2A}$$

PKT for each OD pair and mode are thus calculated by multiplying the entries of the mode specific trip matrix by the respective link of the network:

$$PKT_{ij}^k = T_{ij}^k * D_{ij}$$

Depending on the modes, the activity needs to be reported in different units to the next step Externalities. For the modes car sharing, car as a driver, walking, bicycle and EBike, VKT equals PKT. For the mode car as a passenger VKT is set to zero, because the VKT are already accounted for
within the car as a driver and carsharing category. The activity of mode PT, is reported as PKT.

To estimate the VKT for Taxi and Shuttle the operational data provided by the operator is utilized. A curve estimation based on the reported monthly averages of VKT customers per day is carried out. As the marginal increase of VKT over customers are assumed to decrease with the number of customer power, logarithmic and for comparison linear curve estimation are considered.

I: Emission Factors

Walking and cycling do not lead to any emissions and can be thus dropped from any further consideration within this phase. The mode category ‘Other modes’ is expected to be negligible. With no further information on the private and company car fleet, emission factors for the modes car sharing and car as driver are drawn from literature, more precisely from the online version of the Handbook emission factors for road transport (2019). HBEFA is produced by INFRAS on behalf of several national agencies among others Trafikverket, the Swedish transport agency. HBEFA calculates emission factors based on an extensive range of vehicle, situational and environmental conditions including national settings such as fleet composition and climate. It is a traffic situation model and thus requires VKT data per driving situation as input (Smit et al., 2010) the online version only distinguishes between cold start excess emissions factors $EF_{cold start}^{car} [gCO_2/Trip]$, which occur when the engine is started (INFRAS, 2019) and emission factors for generic driving $EF_{hot}^{car} [gCO_2/VKT]$. Both factors are applicable as engines of private cars are assumed to be cold, when used for on-site trips.

The only option for on-site PT trips are regular urban bus lines. The emission factor for urban busses $EF^{PT} [gCO_2/PKT]$ is extracted from paper investigating the status of the Swedish bus fleet with respect to decarbonization. The reported emission factors date to 2013. (Xylia and Silveira, 2017)

The operator of CMaaS provides fuel consumption data for the vehicles used for Shuttle and Taxi. Combining this data with fuel specific emission factors retrieved from an analysis of emission factors of fossil fuels carried out by the German Environment Agency (2016), fleet-specific emission factors are calculated ($EF_{Shuttle}^{Diesel}, EF_{Taxi}^{Petrol} [gCO_2/VKT]$). For the Taxi fleet, additional emissions occur through use of electrical energy for charging of the battery. It is assumed that as soon as the daily VKT of Taxi exceeds the
electrical range of the battery, the full electrical capacity of the battery is reloaded overnight. If it stays below, only the respective percentage is reloaded. The emission factor for electrical generation in Sweden $\text{EF}_{\text{El}}^{\text{Taxi}} [g CO_2/kWh]$ is drawn from the European Environment Agency (2019).

**J: Externalities**

The TTW GHG emissions are calculated as shown in equation (1) applying the partly researched and partly estimated emission factors per mode $EF^k$ and the fitting representation of estimated activity per mode $A^k$.

### 6.2.1 Selection of Category Variables

According to McNally (2008) category variables are supposed to discriminate significantly between different personal mobility types. Beyond they need to be policy sensitive and generally available. Ortúzar and Willumsen (2011) further specifies how these category variables are identified:

1. Identification of all variable, which might be linked to differences in personal mobility behavior.

2. Initial analysis of mobility behavior to exclude variable with no explanatory value, by comparison of mobility behavior among categories differentiated by these variables. This process is enhanced by testing whether their differences are statistically significant.

3. Detailed analysis of mobility behavior identifying variables that define similar categories. Unnecessary variables, which produce no significant improvement in explaining the variances in the mobility behavior are excluded.

While Ortúzar and Willumsen applies this category analysis only to trip rates, this study applies this concept to trip rates in combination with destinations (compare A: Trip Rate to Destinations) and additionally to mode shares (compare D: Mode Share per Zone). Thus, the personal mobility behavior under review are trip rate, destination choice and mode choice and are analysed as follows:

Firstly, possible differences in mobility behavior are identified by extensive descriptive statistics. Applying suspected meaningful stratifications in person types by socio-economic and location-based
variables. Variables, which result out of this preliminary analysis as potentially meaningful for the classification, are tested for significance through standard hypothesis testing. Classification variables explaining variances in trip rate are tested for differences between two means of independent samples. Classification variables explaining variances in destination and mode choice the one-tailed test for differences between two estimators of population proportions choosing a certain destination or respectively mode is applied. For all tests a significance level of 5% is chosen. Methodology and assumptions for testing these hypothesis are taken from Washington et al. (2011) and common practice and are thus not explained in all details. In order to maintain a certain meaningfulness of the hypothesis tests the author further advises against creating sample sizes below $n_i = 25$ through the classification.

To further support the selected category variables, they can ideally be linked to causality with respect to decision-making and mobility behavior. Therefor the stated satisfaction and experiences with CMaaS of the respective categories are visually inspected for differences, which could further support causality of the observed difference in mobility behavior. This step however is only applicable for the investigation of mode choices because the section about satisfaction and experiences in the survey does not feature any questions referring to trip generation or distribution. Additionally, general, and case-specific literature is revisited to check if the observed difference can be linked to any known or suspected causality for mobility decision-making of individuals. In order to exclude the possibility of missing out on any major trends within the descriptive statistics, this process is also reversed, by firstly identifying the key determents for mobility decision-making in literature, transferring these into the case of corporate mobility, and where applicable testing for these hypothesis within the survey responses.

### 6.3 Scenarios

The *Baseline* scenario estimates the corporate on-site mobility and its CO2 emission under the current situation following the under 6.2 *Estimation of GHG Emissions* outlaid methodology. Scenarios serve the quantification of potentials for reduction in CO2 emissions, by implementing certain measures. Scenarios are formulated based on observations in the descriptive analysis, which were identified to cause disruptive change in the mobility behavior of the employees. Limits to the possible implementation of scenarios are set by the eventual model specifications and its thereof
resulting reactivity to implemented measures. Beyond, Hesselgren et al. (2019) stated, that the corporate culture in the given case is promoting face-to-face meetings. As this policy is unchallenged by the corporation, this thesis also leaves the trip generation and distribution untouched with respect to the development of potential scenarios. Within these limitation, reduction in GHG emissions can thus either be induced by technological change in vehicles away from fossil fuels or by a modal shift to modes, which emit less emissions (Karlsson et al., 2017).

6.4 Software Usage

Software used for the analysis and processing of the data within this thesis are ArcGis Desktop (ESRI, 2018), SPSS Statistics (IBM, 2017) and Matlab (© 1994-2019 The MathWorks, Inc., 2018).
7 Results and Discussion

In the following paragraphs the results of the applied methodology are presented and discussed. Information on addition of variables is provided under Annex 3. The chapter starts with a descriptive analysis of the available data. In the second chapter, the results of this descriptive data are combined with results of previous research and concepts, to transfer the observed phenomena into causal connections and eventually defining the classification into person categories with respect to mobility behavior. Building on this analysis, the overall on-site mobility and resulting GHG emissions are estimated in Baseline. Eventually, two Scenarios are developed, and finally compared to the Baseline.

7.1 Descriptive Statistics

The descriptive statistics is structured according to the type of information as previously categorized to socio-demographics, mobility-related, operational data and experience and satisfaction with CMaaS.

With respect to all data sets, it is important to notice, that the period during which the responses for Survey 3 was collected overlaps, with the Swedish summer holidays, which results in much less employees being on-site and consequently less congested traffic situations. Moreover, due to the same reason, CMaaS was not in service from July 13th to August 11th, 2019.

The survey under focus (Survey 3) was distributed through E-mail among 1995 employees from July 5th to September 15th, 2019 and 422 responses were collected. As mentioned, two additional cross-sectional surveys had been conducted among employees before. Survey 1 yields 433 responses and was carried out from April to June 2018, around the implementation of CMaaS. Survey 2 yields 354 responses and was carried out from October to December 2018. Even though the time period for collection of survey 3 overlaps with the Swedish holidays resulting in the indicated effects on the traffic and availability of CMaaS, the questionnaire asked for general corporate travel practices and satisfaction with CMaaS and is thus still meaningful for the corporate mobility system. Nonetheless, it must be stressed, that part of the responses have been given under the impression of a currently less tens traffic situation and CMaaS being out of service.
Differences between Surveys

When looking at the available data across all three surveys (compare Annex 2), it is apparent that socio-demographic and mobility related questions are mostly identical over all three surveys, while experience and satisfaction with CMaaS is only available in Survey 2 and 3, and is not entirely comparable between those two.

With respect to the mobility related questions, the multiple response sets differ from survey to survey. The on-site mode response sets are almost identical. Survey 1 only misses the option EBike. Both, survey 1 and 2 do not distinguish between car as driver, car as a passenger and car sharing.

When applicable, the same variables as described under Annex 2 have been added to survey 1 and 2, to create uniform data sets over all three surveys.

7.1.1 Socio-Demographics

The record on all employees holds 13,658 workers. Survey 1 provides answers of 433 employees, survey 2 of 354 and survey 3 of 422, and are thus comparable to each other with respect to the sample size. The respondents represent between 2.6% and 3.1% of the total employees. As shown under Annex 3 the surveys adequately represent the age distribution among employees. With respect to the in Table 2 listed margins of generic characteristics within the surveys, it is apparent that blue-collar workers are underrepresented in all three surveys. Beyond, female employees are overrepresented by a margin of 8% in survey 3. Correcting for blue- and white-collar workers, women are still overrepresented by 5.6% among blue- and 5% among white-collar workers. The manager levels are well represented by the surveys. Keeping these differences in mind, the surveys can still be considered representative for the population.
Table 2: Comparison on descriptive statistics of survey 1 (N=433), survey 2 (N=353; Missing=1), survey 3 (N=422) and employees (N=13,658).

<table>
<thead>
<tr>
<th>Variable and Value</th>
<th>Survey 1</th>
<th>Survey 2</th>
<th>Survey 3</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample Margin (%)</td>
<td>Sample Margin (%)</td>
<td>Sample Margin (%)</td>
<td>Population Margin (%)</td>
</tr>
<tr>
<td>Gender</td>
<td>female</td>
<td>25</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>Manager Level</td>
<td>Manager second order</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Manager first order</td>
<td>10</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>No manager</td>
<td>88</td>
<td>90</td>
<td>88</td>
</tr>
<tr>
<td>Blue- or White-Collar</td>
<td>BC</td>
<td>16</td>
<td>20</td>
<td>12</td>
</tr>
</tbody>
</table>

Records on the respondents’ affiliation to a specific corporate unit are on the one hand too divers, to yield meaningful sample sizes and are on the other hand not deemed influential on any mobility-related decision-making and is consequently dropped from further considerations. As this thesis focuses on on-site mobility, the information on household composition and location is not further used either. Upon review, none of these records revealed any irregularities.

In order to further understand the dynamics within the employees’ socio-demographic characteristics, Spearman correlation parameters are calculated under Annex 3 (Washington et al., 2011). The difference between blue- and white-collar employees revealed the biggest correlations to the other variables. Beyond the obvious relationship that a white-collar-job is correlated to a higher manager level, the data also reveals a positive correlation between white-collar jobs and higher age or women.

7.1.2 Mobility Behavior

In the beginning of this chapter some mobility preconditions are analyzed. Thereafter, mobility behavior trip rate, destination choice and mode choice and are analysed for potential differences within person types to lay the foundation for the person categorization analysis.

The mobility preconditions, such as access to a car or bicycle and ownership of a driver’s license are comparable over all three surveys, e.g. in survey 3 the
bicycle and car in the household are 80% respectively 82%, and 96% of the respondents own a driver’s license. As exemplified by survey 3 in Annex 3, the percentage of driver’s license holders is increasing over the age.

To calculate the mode share, one deciding factor is usually the car ownership, as it limits or widens the set of options. With respect to on-site mobility though, this car ownership can be replaced by car availability on-site or rather if or if not, the respondent uses car as a driver for his commute. As the scope of this theses is set to on-site mobility, the commuting by car variable can be considered as independent to a certain extend.

The information on the working location also tends to be too divers to hold meaningful sample sizes for all areas on-site (compare Annex 3). But in contrast to the corporate units, the statistics on working location is a vital information for the analysis of the mobility behavior and is thus not dropped from further considerations. The working locations reveal significant differences with respect to blue- and white-collar worker proportions as shown in Annex 4. Based on these observations the working locations are categorized into white- or blue-collar dominated and mixed areas. Gender also differs over working locations but correcting for blue- or white-collar workers this variation is significantly smaller and can thus be considered as secondary effect. Tendentially, the same is true for the age distribution, where the production centers area F, C and D peak at the age interval from 25 to 29, whereas the office area G peaks from 45 to 49.

Information on number of days on-site per week and multi-modal trips per day are not available in survey 1 and 2. Therefore, only the data for survey 3 is represented in Table 3 and discussed in this paragraph. On average, employees are 4.8 days per week on-site, while 91% stated being on-site on 5 days. 8 people stated that they are not on-site at all, and are thus dropped from any further analysis, concerning the on-site mobility. The number of on-site trips per day is at 1.02, while 49% of the valid respondents reported no on-site trips on a regular day. Among the respondents, who are mobile the average amount of trips is 2.00. On average the respondents performed 0.97 multi-modal trips per day. This value accounts for commute and on-site trips, it cannot be used in any direct calculations for on-site mobility but is useful as an indicator for general mobility attitudes. The sample standard deviations for on-site and multimodal trips per day indicate a high amount of dispersion among the employees. Information on the amount of time spent for on-site trips per week is recorded on the ordinal scale and was provided by 412 respondents. 66% of those spent maximal one
hour, 23% from one to two hours and 11% more than two hours per week for on-site trips.

Table 3: Statistics on mobility habits (survey 3).

<table>
<thead>
<tr>
<th>N</th>
<th>Q6: Days on-site per week</th>
<th>Q9.0: On-site trips per day</th>
<th>Q12: Multi-modal trips per day (Commute and on-site)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valid</td>
<td>421</td>
<td>403</td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>4.81</td>
<td>1.02</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td>5.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td></td>
<td>.781</td>
<td>1.555</td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Percentiles</td>
<td></td>
<td>25</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Checking on differences between the surveys for the available amount and time spent for on-site trips, does not reveal any major changes in sample means or medians and standard deviation. Notable, the share of on-site immobile respondents increased from 42% in survey 1 to 48% and 49% in survey 2 and 3.

Validation of Mode Share Estimation

As explained in 6 Methodology - D: Mode Share per Zone computation of mode shares is validated through the comparison of directly stated and computed on-site modes shares in survey 2:
The chart for the estimated on-site mode share is based on 184 respondents, who stated to make at least one on-site trip per day. Interestingly, the 167 respondents from survey 2 who stated under S2.Q6, that they perform no on-site trip on a regular day, still reported under S2.Q18 for all modes a total of 559 on-site trips per week. This represents 26% of the totally reported 2135 weekly on-site trips in survey 2. The biggest absolute differences in percentages occur within car as driver, which is estimated to a 3.3% lower share and Shuttle, which is estimated to a 2.8% higher share. Relatively, the biggest differences in percentage are more concerning. The share of the Taxi service is overestimated by a factor of 0.352 from 5.1% to 5.5%, Shuttle is overestimated by 0.112 and bicycle is underestimated by 0.164, which indicates a reduced meaningfulness of the estimation for small mode shares.

In conclusion, the methodology for the calculation of mode share misses out on a substantial part of on-site trips and tends to slightly overestimate the share of the CMaaS services and underestimate the mode share of car. Nonetheless, it still manages to depict the general tendencies within mode share and in absence of any further information it is a meaningful indicator for differences in mode shares, given that the underlying sample sizes are reasonably large.

**Trip Rate**

The on-site trip rate is analyzed for differences among person types stratified by gender, age grouped by different interval sizes, working location, blue- or white collar and commuting by car as a driver. With respect to mean number
of on-site trips, this process does not reveal any major correlations, except for a peak of 1.6 trips per day among 50 to 54-year-old respondents compared to the overall average 1.05. Tendentially, the trip rate is increasing with age starting from 0.79 trips per day among 20 to 24-year-old, but this development is undercut by a decisive decline from 54 years onwards, to 0.93 trips per day in for 55 to 59-year-old. With respect to working location, two areas are remarkable. On the one hand the area A, which is well connected with a CMaaS station for all Shuttle lines and EBikes, still provides the lowest mean for trips per day of 0.65. Considering the high number of respondents of 130, this appears to be robust, and will be checked at a later stage.

The same tendencies are observed with respect to immobility (trip rate equal zero). Area A features the highest rate of immobile respondents with 60% compared to the overall 48%. Other locations are either not diverging or feature too small sample sizes. It is worth mentioning, that the satellite area G is not featuring any different attitudes when it comes to trip generation. The share of immobile respondents decreases depending on the manger level from 50% among none-mangers to 33% among managers of second order. Interestingly, this does not transfer into a major difference in mean number of trips. Beyond, there is large difference between blue- and white-collar workers, as 68% of the blue-collar workers are immobile compared to 46% of white-collar workers. Among the 13 blue-collar workers, who reported on-site trips the mean of 4 trips per day is remarkably high compared to the 1.9 trips per day among white-collar workers. This high value results mainly from three respondents, accounting for more than half of the totally reported trips in this group. Therefore, it is very questionable if these respondents are representative for the group of mobile blue-collar workers. Other characteristics under investigation like commute by car or gender do not reveal an association to trip generation.

**Destination Choice**

Comparing the destinations to the working location of the employees reveals that the attractiveness of the destinations is not directly correlated to the number of employees (compare Annex 3). Especially the area N is remarkable as it only hosts with 0.3% the lowest share of all employees but ranks the 5th highest among on-site destinations (Q10), mentioned by 15% of survey 3 respondents. Area C on the other hand ranks with 9% of employees as third biggest area, while only being mentioned as destination by 12% of the respondents, the 6th rank.
Figure 5 plots the proportion of respondents who ticked a certain destination over the corresponding distance between origin and destination. It does not reveal any correlation. Filtering for mobile respondents even increases the scattering of values. Thus, it is concluded, that the on-site trips distribution is not primarily determined by distances between origin and destination.

Figure 6 shows the proportion of trip destinations for different origin zones (working locations). The sample sizes for working locations, quickly shrink with higher rate of differentiation. Only the areas A, B and E provide sample sizes above or equal to 25 respondents. The most common destinations are the areas A, B and E in this order. The strong bidirectional link between the areas A and E is also highlighted, as both areas attract most of the other area’s respondents. The blue-collar areas do attract far less respondents than the white-collar ones.
Attempting to increase the sample size by aggregating the working locations into for mobility behavior relevant groups does not reveal significant differences. Three different categorizations were tested. Two, focused on the transport network or rather the available CMaaS services. Firstly, categorizing the working locations by availability of CMaaS services (EBike (Yes/No) | Number of Shuttle lines) and secondly by differentiating the access through the Shuttle line itself (Blue/Red /...). The third categorization aims at the type of working area with respect to blue- or white-collar dominance as presented under Annex 4. The destination choices within these categories are compared in Figure 4. It reveals a noticeable difference in destination choice and thus indicates that different person mobility types might be identified through this categorization. The categorizations focusing on transport network do not reveal any correlations.
Mode Choice

When it comes to the modes used on-site there are two variables available for assessment. On the one hand the direct response to Q11, if or if not, a specific mode is used by the respondent (Figure 8) and on the other hand the according to Methodology - D: Mode Share per Zone computed mode shares (Figure 9).

*Figure 7: On-site destination trip shares by working location categorized by blue- or white-collar. (Survey 3; N<sub>Total</sub>=202; N<sub>min</sub>=N<sub>blue-collar</sub>=24)*
During survey 1 EBike was not a valid answer, just as survey 1 and 2 did not provide the option for car as passenger or carsharing. Nonetheless, as shown by Figure 8, the generally used modes do not differ over the three surveys. Only walking increases drastically in survey 2 by 16% but bounces back below the original level in survey 3, which is quite astonishing as survey 2 was conducted during autumn and winter, while survey 1 and 2 were carried out in summer. It might be due to the different type of question concerning on-site modes in survey 2 (compare Annex 3). But simultaneously, survey 2 does not reveal any further anomalies, which is contradicting to this hypothesis. The distinct increase in walking also transfers into the on-site mode share, as shown in Figure 9. The mode share for survey 2 represents the aggregate of directly stated trips per mode by the respondents.

Figure 8: Comparison of used on-site modes by survey. (N₁=433; N₂=305; N₃=419).
The sample sizes for the mode shares in survey 1 and 3 are smaller, because the calculation only accounts for employees, who are mobile on-site. Comparing, the from a data perspective homogeneous mode shares in survey 1 and 3, it can be stated that the share of CMaaS slightly increases to 41%, thanks to the addition of EBikes. Car overall increases even more to 44%. But as the option was added, it is not entirely clear how respondents formerly reported their car trips as passengers or as carsharing, which also includes the use of department cars.

Due to this inconsistency in the data and lack of differences in mode choice from survey to survey, it is not possible to extract a change in mode choice over time through these. Therefore, the focus shifts to identifying potential category variables for different person mobility types within survey 3. Using the same independent variables as applied to the on-site trip frequencies above: Gender, age, manager level, commuting by car, blue- or white-collar worker and working location. Except for the blue-collar workers and the edges of the age intervals, the sub-samples hold close to or more than 25 respondents, who performed at least one trip per day, and are thus meaningful for sub sequential statistical testing. Categorization into blue- or white-collar works is dropped from the mode choice analysis.

The categorization into manager and none-managers does not reveal any differences in the on-site mode share. Figure 10 depicts the mode share between female and male, which differs especially with respect to use of the CMaaS Shuttle service.

Figure 9: Comparison of on-site mode shares by survey (N1=246; N2=184; N3=205).
Similarly, Figure 11 shows that the mode choice also differs among those respondents who use car as a driver for commuting (67%) and those who do not (33%). As discussed before, this distinction replaces the car ownership for on-site trips. It is worth noticing, that commuting by car as a driver does not automatically exclude other commuting responses for each respondent. Interestingly, 7 respondents who stated not to use car as a driver for commuting, still stated that they use car as driver for on-site trips, which results in 13% mode share in this category.

Figure 10: On-site mode share by gender (Survey 3; N_{female}=69; N_{male}=136)

Figure 11: On-site mode share by commuting by car as a driver (Survey 3; N_{No}=70; N_{Yes}=135)
Plotting the mode share by age reveals that CMaaS, the active modes and PT have a much higher share among younger respondents. Car modes only account for 9% of on-site trips compared to 61% among respondents from 50-54. For the other age intervals, Figure 12 does not reveal any consistent tendencies for differences in mode share.

The mode shares also differ, when dividing by primary working location. To connect the working location with a meaningful variable for on-site transportation, the working locations are merged according to direct access to CMaaS (service station within 50m). The result of this merge is shown in Figure 13 and reveals a clear tendency to increased use of CMaaS with direct access from working location. Among the areas with an EBike station, the mode share of Shuttle increases with the number of lines, from 9% with one line over 42% with three lines to 44% with 4 lines. There are no working locations with exact two lines. Areas with no direct access to EBike stations, reveal an EBike share of 2% respectively 3% compared to 10% to 13% with direct access. The share of Shuttle is also high among the working locations with EBike stations, because except for the station in area $K$, all the EBike stations are at locations with at least 3 different Shuttle lines.
7.1.3 Operational Data of CMaaS

Within the methodology operational data is used for three main purposes: Firstly, for the validation/correction of the on-site mobility estimations through reported customer numbers by Shuttle. Secondly, for the calculation of VKT from estimated daily trip numbers for CMaaS. Thirdly, for the calculation of service specific emission factors for CMaaS. Thus, the following descriptive analysis lays the groundwork for these objectives.

Operational data is available for the CMaaS on-site modes Taxi, Shuttle and EBike. The operational unit for reporting of customers, VKT and gas consumption differs among the modes. For the Shuttle service, customers are reported per “Buss”. Overall, there are 16 busses in use. Additionally, the number of passengers is also given distinguished by “Shuttle-line”. It is impossible to link those two categories logically, because busses are rotated among the lines and there is no information about the rotation. Thus, these categorizations should be used separately. Number of customers of Taxi are provided as overall total.

Customers

When checking for the monthly reported customers, it is apparent that Shuttle transports the most customers by a large margin, with a monthly mean of 14,809 customers, compared to 1,814 for Taxi and 1,422 for EBike,
when it is available (May through October). Shuttle peaked in March 2019 with 20,995, Taxi in October 2018 with 2,757 and EBike in June 2018 with 2,315. A second observation is the reduced number of customers in July and December for all three services. This is partly due to the reduced number of days the service is available in months overlapping with vacations. Shuttle for example was only in service on 9 days in July 2019 compared to a high of 23 days in October 2018. Even when correcting the number of customers by the amount of days in service as done in Figure 14, the reduction in demand in July remains evident and can thus be allocated to a generally lower demand during this month. The drop in December is less pronounced. Therefore, July is considered as 'not normal', which is important when matching operational data to results from the survey, as the survey asked for 'general' on-site mobility activities.

To generate robust target values for the estimation of on-site trips in later chapters, the total sum of customers over the “normal” 14 months of recorded time period is divided by the total days in service within the same period. For Taxi, this results in 101 customer trips and for Shuttle in 861 customer trips per day. For the on monthly level reported EBike customers, this target value is expressed as a ratio between the two with respect to magnitude of reported trips comparable modes Taxi and EBike from June to October, excluding July. The target ratio is 1 : 0.9 customers (Taxi : EBike).

Unfortunately, only the data over the volatile summer months is available to compare the development of customer numbers over one year. Comparing June through August 2019 to the customer numbers in 2018, it reveals an increase by respectively 28%, 21% and 14% for Shuttle and 10%, 34% and 4% for Taxi. There is no information on the daily availability of EBikes, but compared to 2018, the monthly number of customers decreased by 29% and 42% in June and July and increased by 5% in August 2019. Overall, this data indicates an increase in usage.
For Shuttle, the number of customers distinguished by line are also available. Over the recorded 15 months, 34.8% use the yellow line, 27.6% the blue line, 30.3% the red line and 7.3% the purple line. The shares for each line are very stable over the 15 months and stay between ± 2.6% of these total shares.

**Mileage and Fuel Consumption**

VKT and gas consumption are provided per vehicle, identified by the license plate. These do not directly correspond with the “buss” categorization, within customer numbers and there has been no update on the link between these two descriptions. Taxi is using the VW plug-in-hybrid *Passat SC GTE DSG6* from 2018 and Shuttle is using the VW bus model *Caravan TL 150HK TDI DSG 340* from 2017 and 2018. The cars used for Comfort consume petrol, while the busses in Shuttle run on diesel. The battery of the plug-in-hybrid has a capacity of 9.9 kWh. Based on this information, the VKT and gas consumption can be allocated to the two services. As explained above, the assignment to a specific Shuttle line is not possible based on this data. Beyond there is no documentation on electric charging for the plug-in-hybrid vehicles, nor on the charging of the EBikes at the station.
Based on the reported information about mileage and consumption, variables like VKT per customer, fuel consumption rate and fuel consumption per customer can be calculated on a monthly level. There is neither information on passenger kilometers, nor on capacity or empty vehicle kilometers. The boxplots of the resulting indicators, including the values for outliers are shown in Figure 15 below.

For Shuttle and Taxi, VKT per customer is an indicator for the organizational efficiency of the service with respect to routing and headways, with lower values signalizing a better utilization of the vehicles. Naturally, the on-demand Taxi service is less efficient with a mean of 4.17 km per customer and reveals a wider dispersion in the monthly values, compared to the Shuttle service operating on predefined lines and schedules, with a mean of 3.25 km per customer. Both outliers date from July 2018, which can be explained by a loss in efficiency with lower travel demand during vacations. The monthly means for EBike trip lengths reveal a small range from 1.35 km to 1.81 km, and no outliers, which is expectable for a station-based service, with low overall range.

The fuel consumption rate or fuel economy is an indicator for the technological efficiency of the CMaaS scheme, higher efficiency being
indicated by higher values. Electrical energy use for the charging of plug-in-hybrid cars and the EBikes is not available. As shown in Figure 15 the fuel economy for the Shuttle service, which is running on diesel reveals a low variability. Which is due to the large vehicle fleet of up to 16 busses. The mean fuel economy for Shuttle over the 15 months is 8.97 km per liter diesel. There is no specific reason identified for the outlier which dates to April 2019.

Taxi offers a higher monthly mean for fuel economy of 18.94 km per liter petrol due to the smaller cars and the addition or recuperation of electrical energy by the plug-in-hybrid unit. The boxplot reveals a high variability in the Taxi's fuel economy. This is partly due to the smaller vehicle sample size of three cars. Another effect can be explained based on the first outlier reporting a fuel economy of 24 km per liter petrol. This value dates to July 2018. In this month a total of 3,425 km and 143-liter petrol were reported. While the mileage is calculated through the reported mileage in the end of each month, fuel consumption is calculated through refueled liter petrol. On a month with low total fuel consumption it consequently has a major impact, if a car with a 50-liter-tank is refueled just in the beginning of the following month while mileage is allocated to the previous one. Also, with low daily mileage, the energy added through the nightly plug-in holds a bigger share of overall energy consumption. According to ADAC ECOTEST a fully charged battery can provide 40 km purely electric driving (Brand, 2017). Consequently, the data involving fuel consumption is very volatile on a monthly level, especially for months featuring low daily VKT. It is more reasonable to aggregate the data to bigger intervals. The second outlier of 26.91 km per liter petrol dates to June 2018 and can be traced back to a missing fuel report on one car. As other values are not available on a vehicle level but are aggregated for Taxi in general, all further analysis involving Taxi fuel consumption should exclude June 2018.

In order to estimate a robust fuel economy for the calculation of emissions factors later in this chapter, the uncertainty factor of point in time for refueling is eliminated by calculating the fuel economy over the sums of fuel consumption and VKT during the entire available time period. For Shuttle this results in a fuel economy of 8.915 km per liter diesel. In the case of Taxi June 2018 is excluded, which results in 18.122 km per liter petrol. According to the ECOTEST, the average fuel economy is much higher at 26.32 km per liter. The test results also state, that that the consumption for the plug-in hybrid is highly dependent on the driving style and driving conditions. Being well below the reported averages by ADAC the reported fuel economy indicates that most of the Taxi mileage is performed in the
hybrid mode, which features consumption from 17.5 km per liter for rural and 20.8 km per liter for urban driving conditions. This is reasonable as the plug-in range is stated with approximately 40 km and the daily km per Taxi vehicle are on average at 132 km. (Brand, 2017)

The fuel consumption per customer combines the service and technological efficiency in one indicator, indicating a higher efficiency by lower values. Involving the fuel consumption, it implies the same uncertainty with respect to time of refueling as described in the paragraph above. All outliers except for the one with 0.26 liter per customer can be allocated to this volatility. The exception dates once again to April 2019 and cannot be resolved. The difference in fuel types aside, the technological advantages of the Taxi fleet overcompensates the lack in organizational efficiency as the mean fuel consumption per customer is 0.22-liter petrol for Taxi and 0.36-liter diesel for Shuttle.

Checking for timely trends among these indicators, by plotting them over months does not reveal any further insights besides the increased variation during summer vacations due to refueling uncertainties and decreased demand. In contrast, Figure 16 reveals that for Shuttle and Taxi the VKT decrease with increasing customer numbers, which indicates an increase in efficiency. For the bus service Shuttle, this is expectable as VKT is more independent of demand, thus with increasing customers, the ratio decreases. With respect to the Taxi service, this decrease is more remarkable. It indicates that the routing is performed efficiently and profits from scale effects. The stepper slope of the R²-regression compared to Shuttle can be associated to the poor efficiency with few customers. Expectable, EBike service reveals no scale effect.
7.1.4 Experience and Satisfaction with CMaaS

Besides the on-site mobility habits, survey 3 also focuses on the experience and satisfaction with CMaaS. As discussed before some of the questions within this category are identical to survey 2 (compare Annex 2), but the focus of this analysis lies on different user groups within survey 3. Annex 3 also presents the survey responses to all questions concerning experience and satisfaction with CMaaS. Table 4 defines the sample sizes of the corresponding questions concerning Shuttle, Taxi, EBikes and CMaaS in general. Except for the CMaaS questions, respondents who answered these questions positively were asked follow-up questions. Especially, for the questions asked to EBike users and none-users of CMaaS, the sample sizes can quickly render meaningless, when applying further classifications.
Table 4: Usage of CMaaS among respondents. (Survey 3; N=20; N=25; N=414; N=408)

<table>
<thead>
<tr>
<th>Q</th>
<th>Count</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q15: Have you used the Shuttle service within the last year?</td>
<td>Yes</td>
<td>340</td>
</tr>
<tr>
<td>Q20: Have you used the Taxi service within the last year?</td>
<td>Yes</td>
<td>150</td>
</tr>
<tr>
<td>Q25: Have you used the EBikes service within the last year?</td>
<td>Yes</td>
<td>100</td>
</tr>
<tr>
<td>Q29: Have you used some of CMaaS services within the last year? (App, Taxi, Shuttle, Commuter Bus)</td>
<td>No</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>313</td>
</tr>
</tbody>
</table>

The responses on experience and satisfaction with CMaaS are not discussed in such a holistic manner as the mobility-related ones, because they are rather used to support selective points in the following chapters. The formerly introduced classification of the working locations into access categories to CMaaS can be validated based on the reported access times to Shuttle and EBike. The answers are presented in Figure 17.

![Access to CMaaS](image)

Even though the sample for EBike station is bias, as it is only asked to people who use the service it still proves that the classification is valid, because respondents who's working location is classified to have no direct access to the EBike station, stated to need more time to reach the next EBike station.

7.2 Detailed Investigation of Category Variables

To investigate the observed differences among person types in on-site mobility behavior hypothesis are build based on the descriptive analysis.
These are tested for statistical significance, and subsequentially inspected for causality based on expressed satisfaction or experiences and references in literature. Once again, the analysis addresses the categorization decisive mobility behaviors.

**Trip Rate**

Based on the descriptive analysis, hypotheses have been formed with respect to differences in mean trip rate (Q9) among user distinguished by age (under 35), blue- or white-collar worker and manager or none-manager. The distinction by blue- or white-collar worker and manager or none-manager do not reveal a significant difference in mean trip rate at a 5% level. Respondents under 35 years are found to be less mobile featuring a \( p \)-value of 0.009 on a one tailed test, with equal variances assumed. The respective mean on-site trip rate are 0.75 trips per day for under 35-year-old respondents and 1.15 trips per day for older. This cannot directly be connected to general observations in mobility behavior, which do not feature a specifically low number of trips per day in this age group in Sweden (Trafikanalys, 2017). In the corporate context, this could be allocated to an increasing network between employees and higher career status the longer they are with a corporation. Also, the age group above 35 is in no means homogeneous in the mobility rate, which makes this cut-off rather random. Therefore, this distinction is only in so far considered, as the estimation should make sure that the age distribution in the sample which the estimators are based on is equal to the age distribution of the population.

Categorizing the respondents by the type of working area into white-collar, mixed, and blue-collar dominated areas to create meaningful sample sizes, does not reveal significant differences in trip rate neither. Interestingly, there is no significant difference at 5% level in mean of on-site trips among respondents who commuted by car as a driver. Reversing this hypothesis test and comparing the proportion of commuting by car as a driver among respondents with at least 2, 3 or 4 on-site trips per day, does not reveal any significant difference at 5% level for any chosen cut point in number of on-site trips. Thus, a higher on-site trip rate is not correlated to a higher probability of having a private care available on site (commuting by car).

**Destination Choice**

The descriptive analysis led to the conclusion, that the attractiveness for destinations within this specific corporate mobility is not directly linked to
distances or number of employees at the destination but is rather dependent on within this survey unobserved conditions, such as trip purpose. As shown under the descriptive statistics, the trip distribution does not reveal any coherent correlations to any observed variables, except for the differentiation into blue- or white-collar workers. White-collar workers reveal a significantly higher proportion of white-collar dominated destinations like area A (one-tailed p-value of 0.000), E (p = 0.001), G (p = 0.000) and H (p = 0.015), while blue-collar workers hold a higher proportion for the blue-collar dominated destination area C (p = 0.002). Once again, this cannot be linked to references in literature, but especially for white-collar workers it is assumed to be reasonable, that trips to other white-collar dominated areas are more common to take part in meetings. Unfortunately, there are not enough responses by blue-collar workers in survey 3 perform this analysis for specific destinations, which is necessary for the overall estimation of on-site mobility. But to extract some part of this information destination choice is categorized by the formerly introduced stratification by white-collar, mixed and blue-collar areas (compare Annex 3).

Within this thesis, trip rate and destination choice are estimated simultaneously through the factor $t^j(h_1)$ for a specific person type $h_1 \in H_1$ as explained under 6 Methodology - A: Trip Rate to Destinations. Because the analysis of the trip rate is unable to establish person categories, the categorization within destination choice is the only classification and is follows: $H_1 = \{\text{white-coll}, \text{mixed}, \text{blue-coll}\}$. It is important to notice, that this classification refers to entire areas, which are either white-collar, mixed or blue-collar-dominated.

**Mode Choice**

Significant differences in reported mode choice at a 5% level could be observed for the following socio demographic differentiations:

- Female respondents feature a higher usage of Shuttle ($p = 0.025$),
- Respondents under 35 feature a higher usage of Taxi ($p = 0.011$) and Shuttle ($p = 0.000$), and a lower usage of car as driver ($p = 0.000$)
- Managers feature a higher usage of car as a driver ($p = 0.000$)
- Blue-collar workers feature a lower usage of CMaaS (for all: $p = 0.000$)
In order to investigate the reasons for theses observed differences in mode choice for different subsamples the satisfactions and experiences with CMaaS are analyzed along the same subsamples. Separating these reported satisfaction and experiences by gender does not reveal any differences which could further reason the observed differences in mode choice. The investigation in causality for lower usage of CMaaS among blue-collar workers does not yield any further conclusions. Firstly, the sample size of responses is with 15 very small. Secondly, these 15 respondents even reveal a higher satisfaction with CMaaS than white-collar workers. Due to this lake of reasoning and consistency, both variables are dropped from further consideration, but samples for estimators should make sure to adequately represent the gender distribution of the company, to account for this difference.

Varela et al. (2018) also identified young people from 18 to 24 years to be more likely in the shared-mobility oriented class, which was allocated to financial reasons and lifestyle choices, even though the age group does not match exactly. While the satisfaction section of the survey does not support any causality with respect to lifestyle, such as different environmental attitude (Q32.5) or demands on flexibility (Q32.3), the financial aspect can be supported as shown by the following answers to Q32.4 (Figure 18). The proportion of younger clients using CMaaS due to economic reasons is higher than among older clients.

![Figure 18: Responses to Q32.4 by age group. (Survey 3; N = 314)](image)

Further, the paper also identified managers to be more likely in the car-oriented class, as they are more time constrained. Questions targeting the
link between CMaaS usage and flexibility (Q32.3) and time efficiency (Q32.6) do however not reveal a difference among mangers and none-managers.

In order to generate meaningful sample sizes for investigating mode choices based on location the formerly introduced classification of working areas into access categories to the CMaaS is applied. In the following comparison, the category none, which only applies to the working area M, is excluded, as the sample size is too small. Firstly, areas with direct access and no direct access to EBike station are compared:

- Respondents with access to EBikes stations feature a by 0.216 higher proportion of EBike usage ($p = 0.000$)
- Respondents with access to EBikes stations also feature a higher proportion of Shuttle usage ($p = 0.000$)
- Usage of car as a driver is higher with no access to EBikes ($p = 0.0015$)

The distinction between locations with access to EBike stations and 4 vs. 3 or 1 Shuttle is also justified by the hypothesis tests as the only station with 4 Shuttle lines (area A) features:

- The lowest proportion of car as a driver with 0.25 ($p = 0.001$)
- The highest proportion of Shuttle with 0.78 ($p = 0.021$)
- The highest proportion of the unmotorized modes walking (0.49) and cycling (0.12) ($p = 0.007; p = 0.004$)

This observed differences in mode usage cannot be further rationalized based on satisfaction levels, because no question, which aims at the spatial availability beyond the formerly discussed access time to the services reveal any differences among the categorized working locations. The link between access to EBikes station and usage is evident also on a causal level. The overall use of CMaaS and unmotorized modes in area A can also be explained by the highest connectivity and central position of the working location. The chosen differentiation suggests that the existence of an EBike station also promotes the usage of Shuttle. This link cannot be supported by any reasoning.

Hesselgren et al. (2019) introduces the rational for commuters by car to use CMaaS for internal mobility in order to reduce extensive parking search. Q33.3 targets this hypothesis and confirms this motivation, as 46% of the car commuters strongly agree. But this motivation does not lead to a higher usage of CMaaS, as the usage among those commuters who strongly agreed
to Q33.3 does not differ significantly from those who strongly disagreed at a 5% level.

Commuting by car as a driver has already been suspected as decisive factor for on-site mode choice as it limits the set of available transportation modes on site, and thus effectively replaces the car ownership in conventional transportation modeling. Testing the hypothesis of higher respectively lower on-site mode usages for car commuters \((N = 281)\) and non-car commuters \((N = 141)\) yields the following results:

- Respondents who do not use car as a driver for commuting, feature a higher usage of all none-car modes except for other modes at a significance level of 5% (one-tailed), the highest difference in proportion yields Shuttle a plus by 0.292 \((\pm 0.09)\)
- Respondent who use car as a driver yield a 0.566 \((\pm 0.07)\) higher usage of car as a driver for on-site trips \((p = 0.000)\)

Even though this information is important, it cannot be directly applied for modelling, as survey 3 is the most accurate and recent estimation of commuter modes for employees and is thus already integrated in the derived estimators. But it can be used for the development of scenarios.

Beyond these investigated relations between differences in estimators for different populations, the within survey 3 available information does not allow further studies of lifestyle and social practices, which are generally linked to using practices (Giddens, 1991).

As result, the only applicable and meaningful classification into person types \(h_2 \epsilon H_2\) for the estimation of mode shares \(p^k(h_2)\) as explained under 6 Methodology - D: Mode Share per Zone is by access categories to CMaaS: \(H_2 = \{‘none’, ‘only Shuttle’, ‘EBike Station & 1 or 3 Shuttle Lines’, ‘EBike Station & 4 Shuttle Lines’\}\).

### 7.3 Estimation of GHG Emissions

In the following the total trips per mode and resulting mode shares for all employees on site are assessed for the current situation \((Baseline)\) and for two scenarios, by applying the explained methodology. Assumptions and calculations performed under \(Baseline\) also apply to the scenarios unless stated otherwise.
7.3.1 Baseline

To fulfil the unbiasedness-requirements on population estimators the underlying sample (responses to survey 3) are weighted to accurately represent the employees of the investigated company. As discussed under 7.1.1 Socio-Demographics, blue-collar workers are significantly underrepresented in survey 3, but at the same time significant differences in trip distribution and mode choice have been observed, based on the distinction blue- or white-collar. Thus, blue-collar workers are weighted by a factor of 3.829 to accurately represent the overall work force. This increases the sample size of survey 3 from 422 to 569. Beyond it also decreases the overrepresentation of female respondents in the sample. Further implications of this weighting are discussed under Annex 4.

The structure, how the results of the estimation are presented follows the main steps laid out under 6.2 Estimation of GHG Emissions.

Trip Generation and Distribution

The classification for person mobility types with respect to trip rate and destination choice is classifying all employees of one zone into one of the following classes: \( H_1 = \{\text{white-collar, mixed, blue-collar}\} \). Applying the weighting factor on the sample this leads to the following trip rate factors \( t \) to the destination \( j \) for person types \( h_1 \), whereby person types are defined as employees of areas which are either dominantly white-collar, mixed or blue-collar:
Table 5: Resulting trip rate factors to the destination by person type $t^i(h_1)$. 

<table>
<thead>
<tr>
<th>Destination ($j$)</th>
<th>White-Collar</th>
<th>Mixed</th>
<th>Blue-Collar</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.218</td>
<td>0.092</td>
<td>0.223</td>
</tr>
<tr>
<td>E</td>
<td>0.147</td>
<td>0.087</td>
<td>0.124</td>
</tr>
<tr>
<td>G</td>
<td>0.043</td>
<td>0.096</td>
<td>0.039</td>
</tr>
<tr>
<td>K</td>
<td>0.017</td>
<td>0.019</td>
<td>0.026</td>
</tr>
<tr>
<td>I</td>
<td>0.032</td>
<td>0.128</td>
<td>0.090</td>
</tr>
<tr>
<td>J</td>
<td>0.034</td>
<td>0.023</td>
<td>0.150</td>
</tr>
<tr>
<td>F</td>
<td>0.044</td>
<td>0.012</td>
<td>0.127</td>
</tr>
<tr>
<td>D</td>
<td>0.038</td>
<td>0.033</td>
<td>0.026</td>
</tr>
<tr>
<td>C</td>
<td>0.045</td>
<td>0.016</td>
<td>0.290</td>
</tr>
<tr>
<td>H</td>
<td>0.041</td>
<td>0.008</td>
<td>0.026</td>
</tr>
<tr>
<td>N</td>
<td>0.041</td>
<td>0.135</td>
<td>0.102</td>
</tr>
<tr>
<td>L</td>
<td>0.009</td>
<td>0.061</td>
<td>0.053</td>
</tr>
<tr>
<td>B</td>
<td>0.149</td>
<td>0.116</td>
<td>0.045</td>
</tr>
<tr>
<td>M</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Total trip rate by person type ($t(h_1)$)</strong></td>
<td><strong>0.857</strong></td>
<td><strong>0.826</strong></td>
<td><strong>1.318</strong></td>
</tr>
</tbody>
</table>

Trips to destination which are identified as ‘not on-site’ only accounted for 0.6% of the weighted reported trips in survey 3 and are thus dropped from consideration. It is apparent that the blue-collar areas feature a much higher trip rate, compared to the other two categories which are on similar level. The trip distribution also differs not only from blue- to white-collar but also from white-collar to mixed areas. Area A for instance attracts 0.218 trips per person from white-collar areas while mixed areas only attract 0.09 trips. Area M was not included in the multiple-choice responses (Q10) as a destination and neither appeared among the open answers. But under working location (Q5) it has been added and according to the employees’ data, it also hosts 51 employees. Therefor it is kept as origin working location.

Because employees are classified corresponding to their working location $a_i(h_1)$, which donates the share of employees of a specific category $h_1$ in the area $i$, is either one or zero, according to the classification in Annex 3. Annex 3 also reveals the number of employees per area $N_i$. Applying
\( t^i(h_1), N_1 \) and \( a_i(h_1) \) as in equation (4) results in the preliminary trip matrix, which is shown under Annex 3.

In total this preliminary trip matrix features 10,603 on-site trips per day, which indicates an overall on-site mobility rate of 0.914 trips per person and day. 22% of the trip’s origin from area A, 20.7% from area B and 12.9% from area D. The area attracting most of the trips in descending order are area A, E and B with respectively 21.3%, 14.5% and 14.1% of the trips. Area N stands out as destination attracting 7.3% of the trips, while only 0.3% origin from there.

**Modal Split**

In the next step this preliminary trip matrix is loaded with the mode shares according to the origin zone or rather working location (compare equation (8)). As discussed in the previous chapters, the estimation based on the proximity to CMaaS service stations is the best compromise between significance of mode use proportions, sample sizes and meaningfulness when it comes to mode choice resulting in the person type classes: \( H_2 = \{ \text{‘none’, ‘only Shuttle’, ‘EBike Station & 1 or 3 Shuttle Lines’, ‘EBike Station & 4 Shuttle Lines’} \}. \) Applying the weighting factor for blue-collar workers, results in the following mode share \( p^k \) by mode \( k \) per person type \( h_2 \):

![Figure 19: Mode share per person type \( p^k(h_2) \).](image)

The underlying sample size for the estimators of no-access (none) is with 5 respondents alarmingly small, but due to the unique feature of no-access, it
cannot be included in any other category. This, mode share is only applied to the 51 employees in area $M$. Once again, this classification according to the working locations of the employees leads to $\beta_i(h_2)$ either being one or zero when applied in equation (7).

Overall, the initial loading of trip matrix with the origin specific mode shares results in 376 Taxi, 3,157 Shuttle and 670 EBike trips per day.

**Validation/Correction**

These trip numbers for CMaaS compared to the under 7.1.2 Mobility developed target values for the CMaaS entities. These were 101 for Taxi and 861 for Shuttle. While the ratio between the estimated values fit well with $1 : 8.4$ (Taxi : Shuttle) to the target values’ $1 : 8.52$, the initial estimation is far off with respect to the absolute number of trips, overestimating the number of Shuttle trips by a factor of 3.667 (more exact: $11/3$). With respect to EBike usage the targets value is provided as a ratio between Taxi and EBike usage of $1 : 0.9$. The ratio resulting out of the estimation however, is $1 : 1.78$ and thus far off the target as it even reverses the order. The by the operator monthly reported customers reveal that EBike surpassed Taxi occasionally, but the biggest margin occurred in June 2018, when EBike usage exceeded Taxi by 597 customers or by 35%. These large deviation in the initial estimation and the reported customer numbers are troublesome and will be further addressed under 7.5 Limitations and Uncertainties.

In general, deviations from the target values were anticipated and implemented in the methodology to increase the meaningfulness of the estimation. Even though, the overestimation is very significance the accurate estimation of the ratio between Taxi and Shuttle indicates that the estimation is sound with respect to the relation between modes. This observation however holds not for EBike usage. This could be due to the missing link between destination and mode choice in the underlying survey. In the estimation, the mode share of areas with access to EBike station is applied to all destinations, regardless of existence of an EBike station at the destination, which is necessary in the station based EBike service. In the estimation it is assumed that this unobserved variation is to a certain degree expressed in the mode share by origin area, as the stated use of EBikes results out of the availability of EBike stations at the chosen destination.

The correction of the estimation to the reported data is performed after trip generation and distribution by multiplying the preliminary trip matrix with the correction factor $CF$, resulting out of the ratio between initial trip
estimation and reported customer numbers for the Shuttle service. In this case \( CF = \frac{861}{3157} \approx \frac{3}{11} \approx 0.273 \). This reduces the overall estimated on-site trips to 2,892, which is synonymous with an average trip rate of 0.4. As reported above the mean on-site trip rate among the 403 respondents of survey 3 is 1.02 on-site trips per day. Once again, this will be discussed in the end of the chapter.

As explained under 6.2 Estimation of GHG Emissions the origin specific mode shares (\( p_i^k \)) remain unchanged by the correction and are once again applied to the now corrected trip matrix. Mode-specific trip matrixes are the result of this step. This output suggests a high resolution of possible interpretation, but due to the missing link between destinations and mode-choice in the underlying survey, the results are more meaningful with respect to origins. Results are presented in the end of this chapter next to the scenarios.

**Assignment**

The route assignment, applying the network to the mode specific trip matrixes, results in a total of 4,364 passenger kilometer traveled (pkt) per day or an average trip length of 1.51 km. The highest amount provides the mode car as a driver with 1.767 km. Depicting the passenger-distances traveled by origin areas as done in Figure 20, reveals that area B generates the most passenger kilometers by a large margin even though it features a similar number of employees as area A. This can be allocated to the fact that employees from area A have a very low trip rate and most of their trips are to the close by area E. The remote working area G also generates high amount of passenger kilometers as trips are naturally longer.
Besides these general observations, Figure 20 also allows the identification of potentials and effects for scenarios. As trip generation and distribution will remain untouched by the scenarios, the total passenger distances per zone will remain the same. Thus, areas with high total amount of passenger distances by car modes reveal the highest potential for effects of implemented measures.

Externalities

GHG emission of the car modes and PT are calculated based on the estimated passenger distances and generic values for tank-to-wheel (TTW) GHG-emissions for the respective mode. Car trips as passenger are allocated to car trips as driver, resulting in an occupancy rate of 1.055 persons per private vehicle. The accessible online version of HBEFA offers emission factors for Sweden aggregated over the entire passenger car fleet for 2015 and 2020. These values are interpolated, resulting in the applied emission factor of $EF_{\text{car}}^{\text{tot}} = 149.396 \text{ gCO}_2/\text{VKT}$ and $EF_{\text{car}}^{\text{start}} = 2,186.226 \text{ gCO}_2/\text{Trip}$. For on-site trips, with a maximum distance of 5.2 km, the car emissions will thus mainly result out of the start emissions.
There is no information on the charging of EBikes and according to the supplier, it is not feasible to estimate the energy consumption through the mileage as it is too dependent on unobserved factors, such as chosen level of assistance. Considering the in relation to other modes minor energy consumption per kilometer, the shorter trip distances and the low CO$_2$ emission intensity of 13.3 gCO$_2$ per kWh for electric generation in Sweden (European Environment Agency, 2019), GHG emissions by EBike usage are not further investigated.

The curve estimation for modeling of VKT is using 15 reported monthly averages of VKT and customers per day. All estimations performed poorly on a statistical level (compare Annex 5), which indicates that there is plenty of unobserved noise when it comes to VKT. But in the absence of more information and the need for a modelling of VKT through the customer numbers, the estimation by a logarithmic function is chosen for both services featuring a R-square of 0.228 and 0.16 for Taxi and Shuttle. Application of the estimation is only valid based on customer numbers in proximity to the reported range of 62 to 120 for Taxi and 539 to 1,000, as larger deviations in customer numbers could lead to addition or reduction of vehicles, which is not included in the model.

Resulting fuel consumption applying the under 7.1.3 Operational Data stated estimators for fuel economy, are used to calculate the CO$_2$ emissions based on generic emission for diesel and petrol (3.183 tCO$_2$/t-petrol and 3.168 tCO$_2$/t-diesel) (German Environment Agency, 2016). Combination of these values results in effective emission factors of 131.29 gCO$_2$/VKT for the Taxi fleet and 295.83 gCO$_2$/VKT for the Shuttle vehicles.

Even though, the emissions resulting from electric energy generation used by the plug-in-hybrids does not directly qualify as TTW emission, it is still included in the analysis. They are estimated based on the capacity of the batteries and the emission factors for electric generation in Sweden of 13.3 gCO$_2$/kWh (European Environment Agency, 2019). If the daily VKT by Taxi exceeds the electric range of 40 km per vehicle, it is assumed, that the 9.9 kWh battery (Brand, 2017) is fully loaded overnight, resulting in 395.01 gCO$_2$ per day for the three Taxi vehicles. Are the daily VKT below the 40 km per vehicle, this value is applied proportionally. Once again, the results of these calculation are further discussed when compared to the scenarios under 7.4 Comparison and Discussion of Scenarios. An overview over all resulting emission factors are given below.
Table 6: Applied emission factors (EF).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Emission Factor</th>
<th>Unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi</td>
<td>131.294</td>
<td>gCO₂/VKT</td>
<td>German Environment Agency, 2016</td>
</tr>
<tr>
<td></td>
<td>13.300</td>
<td>gCO₂/kwh</td>
<td>Brand, 2017</td>
</tr>
<tr>
<td>Shuttle</td>
<td>295.830</td>
<td>gCO₂/VKT</td>
<td>German Environment Agency, 2016</td>
</tr>
<tr>
<td>EBike</td>
<td>0</td>
<td>gCO₂/PKM</td>
<td></td>
</tr>
<tr>
<td>PT (Bus)</td>
<td>62.000</td>
<td>gCO₂/PKM</td>
<td>Xylia et al., 2017</td>
</tr>
<tr>
<td>Bicycle</td>
<td>0</td>
<td>gCO₂/PKM</td>
<td></td>
</tr>
<tr>
<td>Walking</td>
<td>0</td>
<td>gCO₂/PKM</td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>149.396</td>
<td>gCO₂/VKT</td>
<td>HBEFA, 2019</td>
</tr>
<tr>
<td></td>
<td>2,186.226</td>
<td>gCO₂/start</td>
<td>HBEFA, 2019</td>
</tr>
</tbody>
</table>

7.3.2 Scenario 1: Increased Spatial Coverage

As shown in the previous chapter, the use of CMaaS services increases with improved access to the stations (compare Figure 19: Mode share per person type \( p^k(h_2) \)). Thus, within this scenario the effects of an increased spatial coverage of CMaaS are explored. Potential locations for additional service stations are identified through Figure 21 below. The focus lies on the location for addition of EBike stations. Therefore, the remote areas \( G, H, M \) and are excluded. The area \( C \) features the highest number of employees among the locations with no EBike station. Physically, this area is not as feasible, because it features a distinct gain in elevation and no direct connection to the other areas, which makes it unattractive for cycling. Area \( D \) and \( F \) on the other hand, are situated directly next to each other in the center of the campus. An EBike station already exists 200 m to the east of these areas in front of area \( K \). But as these areas are rather big an additional EBike station with a good connection to destinations has the potential to feature more EBike trips and is thus chosen within this scenario.
As trip generation and distribution is deemed to be predetermined by the corporate activity this scenario has no implication on these steps. The effect of the additional EBike station on mode choice is estimated by upgrading area D and F to the access category ‘EBike Station & 1 or 2 Shuttle Lines’. The results of this estimation will be presented in the end of this chapter, alongside Baseline and Scenario 2.

### 7.3.3 Scenario 2: Decrease in Car Commute

The second significant difference among respondents to survey 3, that could also be logically linked to mobility behavior is distinction in car and non-car commuters (driver). Not commuting by car consequently eliminates the option on-site. As mentioned under Literature Hesselgren et al. (2019) identified the poor integration of the internal with the external transportation system as a barrier for CMaaS usage. While it is impossible to directly simulate a better integration of these systems within this model, because the scope only includes internal transportation, it is nonetheless possible to estimate the effect of a decrease in car usage for commute, which would be the effect of better integration. In order to implement this into the estimation, the development of the mode shares in the Baseline is revisited. They were calculated upon the multiple response set of answers to Q11.
order to assess the potential maximal reduction in car usage for commuting, the following assumptions are made with respect to respondents who stated, to have used car as a driver under Q8 (N_{car}=281):

- Respondents who only ticked car as driver: Either they have no other option and/or their mobility is car centered.
  - Excluded from reduction (N = 185)

- Respondents whose only additional answers are car as a passenger or motorcycle: They are assumed to organized ride sharing and/or their mobility behavior is car centered.
  - Excluded from reduction (N = 20)

- Respondents whose only additional answer for commuting is a mode which is limited to the campus (Taxi, Shuttle, EBike): The only mode used to reach the campus is car. Either they have no other option and/or their mobility is car centered.
  - Excluded from reduction (N = 1)

- Respondents who additionally ticked Commuter Busses, PT, bicycle or walking the entire way, are assumed to have a valid alternative to car as a driver for commuting
  - Available for change (N=75)

Among those 75 respondents who are identified as available for change are 35 respondents who stated to use car for on-site trips. Applying this maximal shift potential, the on-site mode car as driver is set to zero for all these 35 respondents. Based on this mode usage, the mode shares are recalculated according to the methodology in 6.2 Estimation of GHG Emissions - D: Mode Share per Zone. The resulting difference in mode share by access category to CMaaS (p^k(h_2)) are shown in Figure 22. The access category none features no differences in mode shares as none of the respective respondents was available for change. This is reasonable, because employees from this area are more reliant on car for on-site trips. The areas with only access to Shuttle reveal most potential. The subsequentially estimation of PKT and VKT per mode follows the same steps as before. The results are discussed in comparison to Baseline and Scenario 1 in the end of this chapter.
7.4 Comparison and Discussion of Scenarios

Once again as the trip generation and distribution remained untouched by the scenarios, the total number of trips and person-distance traveled remains constant over all the estimations at 2,892 trips and 4,365 PKT. Therefore these number of trips and PKT are compared based on shares.

Figure 23 shows the resulting modes shares for the Baseline, the scenarios and for comparison reasons also the reported mode share of Survey 3. The difference between the survey and Baseline are miner as they are directly projected from the survey results, only correcting for blue and white collar and to a certain extend the working location. In both scenarios the share of the car modes is distinctively decreased from 44% in Baseline to 36%. While the active modes walking and cycling slightly profit from that by increasing by absolute 1.4% in Scenario 1 and 3% in Scenario 2, the main profiteer are the CMaaS services increasing their total shares by respectively 6.3% and 5.0%. Within the CMaaS entities the proportions stay stable. Scenario 1, which estimates the effects of an additional EBike station between area D and F, does not lead to a significant change. This is mainly
due to how the scenario was implemented, upgrading the areas to the higher access category, which also features a significant higher Shuttle and Taxi share, thus all CMaaS entities profit from this implementation. The absolute daily customer numbers for Taxi, Shuttle and EBike increased from respectively 103, 861 and 183 trips in Baseline to 116, 987 and 226 trips in Scenario 1 and to 119, 976 and 195 trips in Scenario 2.

Figure 23: Comparison of resulting mode-shares.

Figure 24 reveals one of the major flaws of the person category approach for the estimation of trip generation, distribution, and modal split. Variation in average trip length among modes only result out of the variation in employees at each working location and variation in mode shares depending on the access level to CMaaS. But this indirect implementation does not result in a significant difference in average trip length per mode, which shows that the estimation does not capture the essential differences among the modes with respect to travel speed. Walking for instance features an average Baseline-trip length of 1.51 km compared to 1.61 for car as a driver.
Nonetheless, the differences in mode shares from Baseline to the scenarios are slightly amplified with respect to person-distance traveled as car as a driver features the highest average trip length. The distinct increase in average trip length for car as a driver in Scenario 2 occurs, because the central areas $D$ and $F$, with shorter trip distances, decrease their car share through the addition of EBikes.

Figure 25 shows the daily passenger-distances, VKT and the resulting TTW CO$_2$ emissions. In the estimation the occupancy rate calculated by passenger-distance over VKT are low for Taxi and Shuttle with 0.37 and respectively 0.46 customers per vehicle. Car overall, combining car as a driver, car as passenger and car-sharing features an occupancy rate of 1.06 persons per vehicle. The occupancy rate for car results directly out of the reported trips, while Taxi and Shuttle utilizes the calculated passenger-distance traveled. The low occupancy rate for Taxi and Shuttle rise out of the simplified distance calculation between two areas. While passenger-distances result out of these straight lines, the VKT for Taxi and Shuttle are based on the reported VKT per customer and are thus based on the real road network and the Shuttle lines. Therefore, occupancy rates for Taxi and Shuttle should not be directly interpreted as such but are rather meaningful when comparing results of different scenarios within this estimation. According to an exchange with the operator of CMaaS the occupancy for
Shuttle is subjectively estimated to be below one. Thus, the calculated occupancy rate is not entirely off unrealistic after all. Due to the difference in occupancy the total VKT for Shuttle are significantly higher than for car even though car holds the highest share off passenger-distance. In the case of EBike, PT, walking and cycling the stated VKT represent passenger-distance traveled. Once again, a stated walking distance of total 612 km daily is highly doubtful.

Emissions for EBike, cycling and walking are zero while the passenger trips are accounted for in the car as a driver and carsharing modes. The total daily CO\textsubscript{2} emission of PT in all three estimations are with 3.2, 3.9 and 3.6 kgCO\textsubscript{2} per day too small to appear on this scale. Even though Shuttle is estimated to produce 50% more VKT than car as driver, its total emissions are only 29% of car as a driver. Shuttle using busses features a higher emission factor per VKT than the average Swedish car fleet. But for car modes the emissions for on-site trips are dominated by the excess start emissions occurring when starting a cold engine. In Baseline 90.1% of the calculated 2,894 kgCO\textsubscript{2} per day can be allocated to the excess start emissions. Thus, the most relevant input for the calculation of car modes’ emissions are the trip numbers. This reduces the negative effects of the poor spatial accuracy of the estimation because both, CMaaS’ and car modes’ emission calculations are mainly based on trips per day. The share of emissions caused by the electric generation for charging of the plug-in hybrids used by Taxi is with 0.7% neglectable. The provided purely electric range of approximately 120 VKT per day on the other hand is considerable, when comparing to the total of 406 VKT per day in Baseline.
With an increase in passenger-distance, the occupancy rates for Taxi and Shuttle increase in both scenarios compared to Baseline, while Shuttle profits more in both cases. Scenario 1 features an increase of 5% and respectively 12% and Scenario 2 of 8% and 12% for Taxi and Shuttle.

Figure 26 shows the resulting TTW GHG emissions per PKT for all modes that could be estimated within this thesis. The car-modes are aggregated into one. PT clearly features the lowest TTW emissions per passenger kilometer. Even though Taxi has the lowest occupancy rate and a low organizational efficiency, it overcomes this disadvantage with the highest technological efficiency deploying plug-in-hybrid vehicles for the service. Shuttle on the other hand suffers from its low occupancy rate of around 0.5 passengers per vehicle. Nonetheless, Shuttle’s CO₂ emissions per PKT are less than half of car mode’s CO₂ emissions.
When comparing the results of the scenarios to Baseline it is once again apparent that the environmental efficiency of Shuttle profits the most of an increase in passengers. Interestingly, Scenario 1 also leads to a distinct decrease in GHG emission per PKT for car modes. This is caused by the increased accessibility of CMaaS in the center of the campus, which decreases the number of short car trips originating from there. Thus, the average car trip length increases, as peripheral areas are not impacted by this measure. Longer car trips are emitting less GHG per VKT because the extensive start emissions are distributed over a longer trip length. Scenario 2 also leads to a slight decrease in GHG emission per passenger-distance for the car modes, because occupancy rate for car trips is highest as passenger trips are promoted by the decreased number of private vehicles on-site.

Lastly, the overall estimated daily TTW CO2 emissions caused by on-site mobility of the 11,590 employees with an identifiable location on-site are presented in Figure 27. The emissions under the current situation are estimated 3.734 tCO2 per day, 78% of the emissions are caused by the car modes, while 1.4% and 21% are caused by Taxi and Shuttle. The estimated emissions under the scenarios are with 3.170 tCO2 and 3.171 tCO2 almost identical. This represents a decrease of 15% from Baseline. In both scenarios the emission shares of CMaaS increase similarly to 1.8% and 25% for Taxi and Shuttle. Through the decreased availability of private cars on-site in Scenario 2, the share of car-sharing and department cars is increased from 6.0% in Baseline to 9.1% in Scenario 2.
It is difficult to compare these results to any other estimation of GHG emissions. Emissions arising from MaaS schemes have only been assessed on the qualitative level but have not been quantified yet. Additionally, as pointed out at several points within the analysis, corporate mobility is unique to the specific corporation under focus and can thus not be compared. Using data from the Swedish Environmental Protection Agency (2018), the on-site emissions are set in a national context: Sweden’s total road transportation emitted 43.28 k tCO$_2$-eq on an average day in 2016, which translates to 4.231 kgCO$_2$ per capita. As estimated, the on-site mobility within this case emits 3.733 tCO$_2$ per day or 0.322 kgCO$_2$ per employee. Thus, compared to an average Swedish resident, the on-site mobility represents 7.6% of his daily emissions caused by road transportation. Considering, that the estimated emissions only account for on-site mobility of the employees on an campus which allows a maximum trip length of 5.2 km and the national on road emissions include all trips private and business related performed by the populations throughout Sweden, the ratio between seems reasonable. This does not validate the estimation but is an indication for a reasonable range and sets the result into perspective.

### 7.5 Limitations and Uncertainties

The limitations of the analysis result mainly out of the available data, the chosen scope and thereof resulting methodology. This has been hinted at throughout the analysis and is now summarized in the following paragraphs. Ortúzar and Willumsen (2011) distinguish between different types of errors in modelling, which will structure the paragraph. The usage of the person
category analysis for the estimation of trip generation, distribution and mode choice is discussed under *Specification Error*. Transfer Errors are omitted from this paragraph because the model is calibrated based on the given case and is thus not using any data from other models or cases.

*Measurement Error*

The underlying data source for estimation of the employee’s mobility behavior - survey 3 - is connected to several uncertainties. Firstly, it is not a travel diary, which would capture the respondents detailed travel behavior within a given time period. Instead, they were asked to describe their ‘general mobility behavior’ on site, by stating average amount of trips per day, common modes and destinations chosen. Additionally, respondents are unable to report trip chains through the survey design. Overall, this leads to inconsistencies within the response data. For instance, many respondents listed destinations and modes for on-site trips but simultaneously reported not to perform any trips on-site on a regular basis. This indicates that respondents were unsure how to interpret the questions. Within this thesis, these contradictions are resolved by ignoring the mode and destination choices of immobile respondents, because it is impossible to quantify them compared to respondents, who stated at least one on-site trip.

An additional uncertainty with respect to responses is the period, in which survey 3 was carried out, which overlapped with the Swedish summer holiday in 2019. Once again, respondents where explicitly asked to describe their ‘general’ travel behavior, but it is unclear in how far the current transport situation of reduced CMaaS availability and reduced traffic loads influenced their answers.

*Sampling Error*

As discussed before, respondents to survey 3 do not accurately represent the overall workforce. Especially blue-collar workers were underrepresented in the responses and are thus weighted with a factor of 3.829 for all responses by blue-collar workers. This has positive effects on the accurate representation of gender proportions and does not affect the trip generation because mean of trip rates shows no significant difference among blue- and white-collar workers. In contrast to the trip generation, trip distribution and mode choice are much more volatile to disruptions through this significant weighting of blue-collar workers. As discussed before, only 13 blue-collar works reported on-site trips. Consequently, the calculation of on-site trips per mode and destination representing 4,778 blue-collar workers is based on
13 respondents. Annex 4 provides a comparison of mode usage between mobile and immobile blue-collar respondents. Upon inspection it reveals a large difference among these subgroups, which indicates that the mobile respondents might not be representative for blue-collar workers.

**Specification Error**

The person category analysis is chosen for the estimation of trip generation, distribution, and mode choice due to the following characteristics of the available information in survey 3:

- The number of trips by mode and destinations are neither quantified, nor connected to each other. Consequently, when several modes and destinations are listed by one respondent, it is impossible to identify the chosen mode for a specific trip. Therefore, the analysis of mode-choice is limited to the characteristics of the trip maker and the conditions at the origin of the trip – his working location.
- Characteristics of transport facilities, such as travel time, cost, reliability are either unobserved or cannot be linked to specific origin-destination and mode combination and are thus not applicable. Beyond, journey characteristics such as trip purpose and time of day are not addressed in the survey design.

Under these a priori conditions of limited information the researcher opts for the ad hoc approach of person category analysis. Besides advantages such as the independents of the cross-classification from the chosen zone system, Ortúzar and Willumsen (2011) also lists several disadvantages of this approach:

- Basic assumption of stable trip rates over time within categories.
- No clear way to choose variables for the categorization. The identification of ideal grouping for mobility behavior based on observed variables is by trial and error.
- For detailed stratification into several categories, large samples are necessary, in order to guarantee meaningful sample sizes within each category.

These disadvantages are apparent throughout the analysis of this thesis. Even though the literature research does not support the use of the person category analysis for the modelling of modal split, it has been applied in absence of other feasible methods. In consequence, this results in a very unreactive transport demand model. Demographics, land-use, and transport supply can only be changed within the given set of categories. Effects of
measures exceeding these categories cannot be estimated by this transport
demand model. This excludes for example a gradual change in the
demographics of the corporation’s employees over time.

Beyond these disadvantages with respect to the general methodology
there are also several critical points within the specification of the transport
demand model, which lead to uncertainties. Firstly, the correction of the
preliminary trip matrix by $CF = 0.273$ is very significant. Allocating the
differences in estimated - survey 3 - and reported - operational data - Shuttle
trips exclusively to the shortcomings in the survey design as done within this
analysis, is unreasonable. The validation of the mode share estimation in
7.1.2 Mobility - Validation of Mode Share Estimation reveals a slight
overestimation of CMaaS modes, but does not indicate such a dramatic
deviation caused by the methodology. Ultimately, the reason for this
deviation remains unresolved and brands the results of the estimation
questionable.

Another source for specification errors is the possible omission of
relevant variables through the trial and error approach. One suspicious
aspect in that regard is the parking situation on-site, which is a major
reasoning of the corporation for the introduction of CMaaS in the first place.
The study does not identify a significant impact of the parking situation on
on-site mode choice.

Other potential specification errors of the estimation arise from the
simple representation of transport supply, through the network. No CMaaS
entities are capacity constrained and the PT network is not modeled at all.
Both simplifications are reasonable, because the estimated occupancy rates
for Taxi and Shuttle are far from their capacity and PT only represents a
neglectable proportion of the on-site mobility, but nonetheless, these
assumptions limit the application of the model to trip volumes around the
known range for these modes, because the effect of large deviations is
uncertain.

The calculation of the externalities can be considered more reliable,
compared to other steps of the estimation, due to the abundance of available
information through the operational data for CMaaS and publicly available
emission factors. However, it is important to point out that the calculations
for all modes are based on different outputs of the travel demand modelling,
which adds another source for errors.
Aggregation Error

In absence of sharply defining variables for classification into different mobility type persons, the chosen aggregations for trip generation and distribution is by type of working location with respect to blue- or white-collar shares. The meaningfulness of this stratification for mobility behavior is unproven within this thesis and is only based on weak theoretical considerations. Consequently, this aggregation is prone to errors. Therefore, this categorization only distinguishes between three types to achieve stable estimators through large sample sizes. Mode choice on the other hand is stratified into four classes by the access to CMaaS entities. This classification showed statistical significance differences in mode choice and is backed up by literature.

The zoning-design of the transport demand model is once again driven by the availability of data. The 14 defined zones are the finest resolutions available for all modelling steps. This leads to aggregation errors especially for big areas such as area $B$, because all trips with origins outside area $B$ are routed to the centroid of area $B$.

Overall, the aggregations performed in the transport demand modelling diminishes the credibility of the model. This is best exemplified with the in Figure 24 represented average trip lengths per mode, which are similar across all modes. Because mode shares are aggregated by origin zones, the mode choice is independent of trip distance, which is unreasonable. Beyond the performed aggregations limit reactivity of the model to measures, as they can only be applied on the level of the respective aggregates.
8 Conclusion

This final chapter of the thesis first presents the conclusions with respect to CMaaS and then projects them onto the general research field of MaaS. The final paragraph lays out future fields of research, which became apparent through this study.

8.1 CMaaS

This thesis sat out to provide empirical data about the impact of an existing CMaaS scheme on emissions of GHG. This is achieved by analyzing the responses to a user survey and the reported operational data of the CMaaS scheme itself. The transportation demand is estimated through a category person analysis. Overall, the daily on-site TTW GHG emissions by the corporate work force is estimated to 3.734 tCO2. While supplying 40% of the on-site trips CMaaS emits 22% of the GHG emissions. Car modes on the other hand supply 45% of the on-site trips and emit 78% of the GHG emissions. Trips with CMaaS emit significantly less GHG compared to car modes. Even though occupancy rates indicate plenty of unused capacities for CMaaS.

The poor performance of the car modes is mainly due to the cold start excess emissions of the engine, which account for 90% of the emissions by car modes. This finding is expectable for such a small campus. Nonetheless, this highlights the advantages of MaaS schemes especially when it replaces short car trips. Comparing the two motorized CMaaS entities Taxi and Shuttle reveals that the on-demand Taxi service emits half as many GHG emissions per PKT compared to the bus service Shuttle. This can be allocated to the higher ecological efficiency of the car fleet used for Taxi, which overcompensates the lower estimated occupancy rate of the on-demand Taxi service. Generally, the occupancy rates of Taxi and Shuttle are estimated to below 0.5 passengers per car. Considering the capacity of 4 for Taxi and 7 for Shuttle, this indicates an inefficient operation of the service. In how far this estimation is accurate could be verified by reported occupancy rates. A reporting of occupancy rates also helps assessing the performance of a specific Shuttle route and would thus accelerate the further development of the service.

Beyond the estimation of the current GHG emissions, this thesis also estimates two scenarios. One is increasing the spatial coverage of CMaaS and
the other is estimating the effect of reduced commuting by car. Both scenarios lead to a shift from car usage to CMaaS and consequently a decrease in GHG emissions by 15%. The increase in spatial coverage is achieved by an additional EBike station in central position of the campus. An additional option for increasing the spatial coverage of the EBike service and thus the usership is the shift from the current station-based to a free-floating system. This would drastically increase the spatial coverage. To realize such a free-floating system, more EBikes would be necessary to insure the availability of EBikes all over the campus. Additionally, operational complexity and costs would increase as EBikes need be returned to charging stations from time to time. The scenario estimating the effects of a reduction in commuting by car provides an indication, how a better integration of external and internal transportation could impact the on-site GHG emissions. Given that a better integration leads to a decrease in commuting by car.

Unfortunately, this thesis fails to establish a comprehensive and reactive transport model, which would allow the testing and interpretation of interactions in land-use, transport supply and thereof resulting GHG emissions. Firstly, this is due to the one-dimensional research objective to estimate one single societal impact category, the total GHG emissions. Secondly, this lack of meaningfulness is caused by the available information in the underlying survey and the thereof resulting methodology. The performed aggregations in the transport demand modelling make the backtracking of GHG emissions to individual decision making impossible. Thirdly, the operational data also lacks with respect to consistency, as different CMaaS entities are reported with different spatial and timely resolution. Also, additional information such as occupancy could significantly increase the possible analysis of the service. Overall, these limitations only allow general results to be used for feedback into the design and conception of CMaaS and MaaS.

8.2 MaaS

While users of the MaaS scheme are shown to emit less GHG emissions per passenger distance traveled than car users, the available user surveys before and after the implementation do not indicate a shift towards MaaS modes. As most of these modes had been available before the implementation of MaaS. Thus, the study is unable to quantify a reduction in GHG emissions through the implementation of MaaS, which is the initially targeted research gap. Concerns throughout literature, that MaaS might induce more travel


due to its unlimited availability, or that it attracts passengers from PT can neither be confirmed nor refuted by the findings of this analysis.

One implication for MaaS in general which can be made based on this analysis is the successful promotion of environmentally efficient transport technology through the scheme. In the given case this technological advantage is even able to overcompensate the organizational inefficiency of the Taxi service. For the specific case, the argumentation that a on demand Taxi service simply replaces trips by private cars and thus does not lead to a decrease in VKT through MaaS cannot be refuted. But as shown, a Taxi service using environmentally friendly technology is emitting significantly less GHG emissions, due to the cold start excess emissions of private cars. This effect is more pronounce when MaaS is replacing short private car trips.

8.3 Future Research

This thesis exposes open questions around MaaS on several levels. With respect to the specific CMaaS scheme under focus a reactive land use transport interaction model applying more sophisticated modelling methods is necessary to truly estimate impacts of the scheme on all levels; individual, economical, and societal. This would enable the researcher to clarify in how far MaaS is able to resolve the urban conflict between increasing transport demand and the need to decrease the negative externalities of transportation. Prerequisites for such a model are detailed transport diaries for calibration. As a minimum such a diary should capture origin, destination, mode, and purpose for each trip. Additional information as time and duration of the trip are useful, but not necessary. Another option would be direct collection of mobility data through the App itself. Secondly, this model would need a more sophisticated network representation ideally imbedded into background traffic loads and available capacities. Especially the parking situation and the interaction of on-site mobility with commuting remain largely unaddressed through this study.

In how far such a detailed modeling of the given CMaaS is necessary to further improve the service is questionable, given the necessary additional costs of such and analysis. Another route of action is testing of variations in the service under close observation of the KPIs. Especially for such a small and well-defined service as the given CMaaS, such an experimental approach might result in more robust results and recommendations for the further development of CMaaS.
Another research gap exposed by this study is the transport demand modelling of corporate mobility in general. Literature offers little support for this specific field, while the analysis revealed significant differences to other land use contexts. In how far the mobility patterns of corporations are too specific to be generalized remains an open question.

Even though this study highlights the benefits of ecological more efficient vehicles, it does not include the production and recycling phase of these vehicles. This is expected to significantly worsen the environmental performance, especially as the on-site mobility itself is not anticipated to reduce private car ownership in the workforce. This is only achieved by addressing on-site mobility and commuting combined.

Lastly, the estimated GHG emissions represent an initial point of orientation for quantification of environmental impacts. Evidently, MaaS schemes are multi-faceted, as they vary on all levels; the land-use and transportation context, and the three key integrations; *Ticket and Payment integration*, *Mobility package integration*, and *ICT integration*. Nonetheless, when these specifications are respected, the environmental performance of schemes are quantitative comparable.
References


generation of travel and transport: Combined Mobility as a service in Sweden, Kombinerad Mobilitet Som Tjänst I Sverige.


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## Annex 1: Indicator Framework CMaaS

### Annex Table 1: Indicator framework - Effects

<table>
<thead>
<tr>
<th>Individual</th>
<th>Organizational</th>
<th>Societal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions</td>
<td>Sustainability Objectives and Targets</td>
<td>Emissions</td>
</tr>
<tr>
<td>Energy Use</td>
<td>Synchronized Transport Solution</td>
<td>Sustainability Targets</td>
</tr>
<tr>
<td>Value of Time</td>
<td>Operation of the system</td>
<td>Quality of Life</td>
</tr>
<tr>
<td>Travel Costs</td>
<td>Work Efficiency</td>
<td></td>
</tr>
</tbody>
</table>

Satisfaction with the Service
Accessibility
Availability

### Annex Table 2: Indicator framework - KPIs

<table>
<thead>
<tr>
<th>Individual</th>
<th>Organizational</th>
<th>Societal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual energy use per year</td>
<td>Corporates Incentives for sustainable travel</td>
<td>Total energy use per year</td>
</tr>
<tr>
<td>Individual GHG emissions per year</td>
<td>Corporate's use of environmentally sustainable vehicles</td>
<td>Total GHG emissions</td>
</tr>
<tr>
<td>Cost of transport</td>
<td>Cost of MaaS related services</td>
<td>Total transport costs</td>
</tr>
<tr>
<td>Perceived accessibility to services</td>
<td>Infrastructure provision</td>
<td>Time Value</td>
</tr>
<tr>
<td>Perceived transport system availability</td>
<td></td>
<td>Percentage of user groups that were satisfied with the services</td>
</tr>
</tbody>
</table>
Annex 2: Survey data

In this Annex the original survey is represented, and the basic processing of the available data provided by the operator as a .xlsx-file into a workable .sav-file are explained. Annex Table 3 presents the Survey 3 (S3) and provides a comparison with Survey 1 and 2 (S1 and S2). It states the question number under S3, the asked questions under Label, the set of valid responses for closed questions under Value, and finally the Type (Numeric or String) and Measure-level (Nominal, Ordinal or Scale). If available, S1 and S2 indicate the corresponding question in S1 and S2. When referring to specific questions in the following, it refers to the question numbers in S3.

The statistical analysis within this thesis is conducted within the IBM software SPSS statistics, Version 25. Value, Type and Measure result out of import tool of the software and following transformations based on a review of the data by me. This process is explained in the following. Upon request, a full documentation of this process in form of SPSS output and syntax files (.spv and .sps) can be provided.

The original data in Swedish and is translated to English. Responses recorded as string remain in the original language. Binary questions are recoded from the original string type answers into numeric type with value labels, e.g. Q3 (Yes / No) and Q35.0 (female/male). Ordinal questions are recoded from the original string type into numeric values from one to the respective amount of valid responses and the corresponding value labels are applied, e.g. Q1 (1 / 2 / 3 / 4 / 5 or more) and Q16 (max 5 min / 5-10 min / 10-15 min / 15-20 min / more than 20 min). Responses on the Likert scale with 5 levels (e.g. Q18), originally recorded as string, are recoded into numeric type from one to five and are labeled ‘1 Strongly disagree’, ‘2 Disagree’, ‘3 Neutral’, ‘4 Agree’ and ‘5 Strongly agree’. Multiple response questions (Q3, Q4, Q8, Q10 and Q11) are coded as multiple response sets. Empty cells for numeric type responses are recorded as system missing. Certain questions also allowed the responses ‘Do not know’ (indicated by a superscript 2) and ‘Do not know / Not relevant’ (indicated by a superscript 3). These responses are recorded as user-missing values. Originally, the response ‘other modes’ to questions about the used modes for commuting and on-site trips (Q8 and Q11) were recorded as string. Looking through these responses it became evident, that most of them could be allocated to modes represented within the given set of responses. This has been done manually and the type of ‘other modes’ has been changed to numeric and the
value labels to ‘Yes’ and ‘No’, in order to have uniform multiple response set for Q8 and Q11. This reduced the number of ‘Other modes’ from 7 to 3 for commute (Q8) and from 9 to 6 for on-site (Q11).

As mentioned before, questions which are available over all three surveys are indicated in Annex Table 3. For these questions the same transformation processes, with respect to Value, Type and Measure are applied, so that corresponding data sets are uniform. It is worth noting, that the set of available transport modes for commuting and on-site trips (Q8 and Q11) differ over the surveys. More importantly, these questions also differed with respect to their nature in S2. Instead of asking the binary questions if, or if not, the respective transport mode is used, S2 asked for the number of trips per week and transport mode. But as the binary response provided in S3 can be computed from the scalar answers in S2, these questions are still listed under S2 in Annex Table 3, but marked with a star. The corresponding question to Q33.3 in S2 is also marked with a star because it also differs between the two survey. S3 asks for the level of agreement to the statement ‘I use CMaaS so that I do not have to search for parking.’ and S2 to the statement ‘I use CMaaS because I do not want to move the car and loose the parking spot’ (S2.Q25.10). While the statement in S3 aims at the parking situation at the trip destination, S2 rather aims at the situation at the trip origin. Nonetheless, both statements set the use of CMaaS in relation with a negatively perceived parking situation on-site and are thus somehow comparable.

Annex Table 3: Original questions and coding of their responses in survey 3 (S3), and comparison with survey 1 and 2 (S1, S2).

<table>
<thead>
<tr>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Label</th>
<th>Value</th>
<th>Type</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td></td>
<td>How many persons live (full- or part-time) in your HH?</td>
<td>1; 2; …; 5 ‘5 or more’</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td></td>
<td>Q1.0</td>
<td>Q1.0</td>
<td>How many children live (full- or part-time) in your HH?</td>
<td>1; 2; …; 5 ‘5 or more’</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q2</td>
<td>Q2</td>
<td>Q3</td>
<td>How old are the children living in your HH?</td>
<td>0-7</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8-14</td>
<td>0 ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15-17</td>
<td>0 ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18 or older</td>
<td>0 ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td>Q4.2</td>
<td>Q3.1</td>
<td>Do you have...</td>
<td>a bicycle in HH.</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td>Q4.4</td>
<td>Q3.3</td>
<td>a driver’s license</td>
<td>o ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td>Q5</td>
<td>Q4</td>
<td>Q5</td>
<td>Where on campus do you have your main working location?</td>
<td>String</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6</td>
<td></td>
<td></td>
<td>How many days per week do you usually work on site?</td>
<td>Numeric</td>
<td>Scale</td>
<td></td>
</tr>
<tr>
<td>Q10</td>
<td>Q14.1*</td>
<td>Q8</td>
<td>Which transport mode do you usually use for commuting to and from work? (Multiple responses)</td>
<td>h) Car as driver o ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td>Q14.2*</td>
<td></td>
<td>i) Car as passenger o ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q10</td>
<td>Q14.4*</td>
<td></td>
<td>a) Commuter o ‘No’; 1 ‘Yes’</td>
<td>Numeric</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>Label</td>
<td>Value</td>
<td>Type</td>
<td>Measure</td>
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<td>---------</td>
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<tr>
<td>Q10</td>
<td>Q14.5*</td>
<td></td>
<td>allowed)</td>
<td>Buss</td>
<td>e) PT</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td>Q10</td>
<td>Q14.6*</td>
<td></td>
<td></td>
<td>f) Bicycle</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td></td>
<td>Q14.7*</td>
<td></td>
<td></td>
<td>d) EBikes</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td></td>
<td>Q14.8*</td>
<td></td>
<td></td>
<td>b) Taxi</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td>Q10</td>
<td>Q14.9*</td>
<td></td>
<td></td>
<td>c) Shuttle</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td>Q10</td>
<td>Q14.10*</td>
<td></td>
<td></td>
<td>g) Walking</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td>Q13.0</td>
<td>Q6.0</td>
<td>Q9.0</td>
<td>How many trips on-site do you make during a regular day?</td>
<td>1; 2; ...; 10 '10 or more'</td>
<td>Numeric Scale</td>
<td></td>
</tr>
<tr>
<td>Q11</td>
<td>Q18.1*</td>
<td>Q11</td>
<td>Which transport mode do you usually use for on-site trips? (Multiple responses allowed)</td>
<td>h) Car as driver</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
</tr>
<tr>
<td></td>
<td>Q18.2*</td>
<td></td>
<td>i) Car as passenger</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q18.3*</td>
<td></td>
<td>j) Carsharing or department car</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td>Q11</td>
<td>Q18.4*</td>
<td></td>
<td>e) PT</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q18.5*</td>
<td></td>
<td>f) Bicycle</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q18.6*</td>
<td></td>
<td>d) EBikes</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td>Q11</td>
<td>Q18.7*</td>
<td></td>
<td>b) Taxi</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q18.8*</td>
<td></td>
<td>c) Shuttle</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q18.9*</td>
<td></td>
<td>g) Walking</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>k) Other modes</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td>Q12</td>
<td></td>
<td></td>
<td>How many multimodal trips do you make per day? (Commute and on site)</td>
<td>1; 2; ...; 10 '10 or more'</td>
<td>Numeric Scale</td>
<td></td>
</tr>
<tr>
<td>Q14</td>
<td>Q7</td>
<td>Q13</td>
<td>How much time do you spend for on-site trips during a regular working week?</td>
<td>1 'max 1 h'</td>
<td>2 '1-2 h'</td>
<td>3 '2-3 h'</td>
</tr>
<tr>
<td>Q22</td>
<td>Q15</td>
<td></td>
<td>Have you used the CMaaS Shuttle service within the last year?</td>
<td>o 'No'; 1 'Yes'</td>
<td>Numeric Nominal</td>
<td></td>
</tr>
<tr>
<td>Q15</td>
<td>Q8</td>
<td>Q16</td>
<td>Label</td>
<td>Value</td>
<td>Type</td>
<td>Measure</td>
</tr>
<tr>
<td>-----</td>
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<td>-------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>How much time do you usually allocate to reach the next Shuttle stop?</td>
<td>1 'max 5 min' 2 '5-10 min' 3 '10-15 min' 4 '15-20 min' 5 'more than 20 min'</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q17</td>
<td></td>
<td></td>
<td>How long does a usual trip with the Shuttle take?</td>
<td>1 'max 5 min' 2 '5-10 min' 3 '10-15 min' 4 '15-20 min' 5 'more than 20 min'</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q18.1</td>
<td></td>
<td></td>
<td>Timetables for the Shuttle are easy to access.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q18.2</td>
<td></td>
<td></td>
<td>The Shuttle follows the timetable.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q18.3</td>
<td></td>
<td></td>
<td>I receive information about changes in the timetable (e.g. Shuttle is not running because of monthly meeting)</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q18.4</td>
<td></td>
<td></td>
<td>I can easily plan my trip with the Shuttle.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q22</td>
<td>Q20</td>
<td></td>
<td>Have you used the CMaaS Taxi service within the last year?</td>
<td>0 'No'; 1 'Yes'</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td>Q21</td>
<td></td>
<td></td>
<td>How long do you usually have to wait for the ordered Taxi at the meeting location?</td>
<td>1 'max 5 min' 2 '5-10 min' 3 '10-15 min' 4 '15-20 min' 5 'more than 20 min'</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q22</td>
<td></td>
<td></td>
<td>How long does a usual trip with the Taxi take?</td>
<td>1 'max 5 min' 2 '5-10 min' 3 '10-15 min' 4 '15-20 min' 5 'more than 20 min'</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q23.1</td>
<td></td>
<td></td>
<td>Information on how to book the Taxi are easy to access.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q23.2</td>
<td></td>
<td></td>
<td>Information about changes or disruptions in the Taxi service are communicated in time.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q22</td>
<td>Q25</td>
<td></td>
<td>Have you used the CMaaS EBikes service within the last year?</td>
<td>0 'No'; 1 'Yes'</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td>Q26</td>
<td></td>
<td></td>
<td>How long does it take you to reach the next EBikes station?</td>
<td>1 'max 5 min' 2 '5-10 min' 3 '10-15 min' 4 '15-20 min' 5 'more than 20 min'</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q27.1</td>
<td></td>
<td></td>
<td>Information on how to book the EBikes are easy to access.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q27.2</td>
<td></td>
<td></td>
<td>Information about changes or disruptions in the EBikes service are communicated in time.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q22</td>
<td>Q29</td>
<td></td>
<td>Have you used some of CMaaS entities within the last year? (App, Taxi, Shuttle, Commuter Buss, EBike).</td>
<td>0 'No'; 1 'Yes'</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td>Q23.1</td>
<td>Q30.1</td>
<td></td>
<td>I do not use CMaaS because the alternatives do not fit my schedule.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q23.2</td>
<td>Q30.2</td>
<td></td>
<td>I do not use CMaaS because the alternatives are not available at my locations.</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q23.4</td>
<td>Q30.3</td>
<td></td>
<td>I do not use CMaaS because I think the app is</td>
<td>Likert Scale, 5 Level</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>Label</td>
<td>Value</td>
<td>Type</td>
<td>Measure</td>
</tr>
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<td>----</td>
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</tr>
<tr>
<td>Q23.3</td>
<td>Q30.4</td>
<td>I do not use CMaaS because I do not have to travel on site.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q30.5</td>
<td>I do not use CMaaS because I am dissatisfied by the service.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
<td></td>
</tr>
<tr>
<td>Q30.6</td>
<td>I do not use CMaaS because a private car is better than the offered services.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
<td></td>
</tr>
<tr>
<td>Q24</td>
<td>Q31</td>
<td>Other reasons for not using CMaaS.</td>
<td>String</td>
<td></td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q25.1</td>
<td>Q32.1</td>
<td>I use CMaaS because of curiosity.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.2</td>
<td>Q32.2</td>
<td>I use CMaaS because of its comfort.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.6</td>
<td>Q32.3</td>
<td>I use CMaaS because of its flexibility.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.3</td>
<td>Q32.4</td>
<td>I use CMaaS because of economic reasons.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.4</td>
<td>Q32.5</td>
<td>I use CMaaS because of environmental reasons.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.5</td>
<td>Q32.6</td>
<td>I use CMaaS because of efficiency/timesaving.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.8</td>
<td>Q33.1</td>
<td>I use CMaaS to plan my trips.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.7</td>
<td>Q33.2</td>
<td>I use CMaaS because I want to reduce my car usage.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q25.10</td>
<td>Q33.3</td>
<td>I use CMaaS so that I do not have to search for parking.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q33.4</td>
<td>I have reduced my private car use since the start of CMaaS.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
<td></td>
</tr>
<tr>
<td>Q33.5</td>
<td>It has become easier to move on site since the start of CMaaS.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
<td></td>
</tr>
<tr>
<td>Q33.6</td>
<td>CMaaS is easy to access for leisure activities on site (e.g. lunch, sports)</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
<td></td>
</tr>
<tr>
<td>Q33.7</td>
<td>Overall, I am satisfied by CMaaS services.</td>
<td>Likert Scale, 5 Level</td>
<td>^3</td>
<td>Numeric</td>
<td>Ordinal</td>
<td></td>
</tr>
<tr>
<td>Q26</td>
<td>Q34</td>
<td>Are there any other reasons why you use CMaaS?</td>
<td>String</td>
<td></td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q25.0</td>
<td>Q27.0</td>
<td>Q35.0</td>
<td>Gender</td>
<td>0 'female'; 1 'male'</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td>Q26.0</td>
<td>Q28.0</td>
<td>Q36.0</td>
<td>Age</td>
<td>Numeric</td>
<td>Scale</td>
<td></td>
</tr>
<tr>
<td>Q27</td>
<td>Q29.0</td>
<td>Q37</td>
<td>Zip-Code</td>
<td>Numeric</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q28.0</td>
<td>Q30.0</td>
<td>Q38.0</td>
<td>Municipality</td>
<td>String</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q29.0</td>
<td>Q31.0</td>
<td>Q39.0</td>
<td>Position in company hierarchy (Chefskod)</td>
<td>1 'Manager with managers below'; 2 'Manager (first order)'; 3 'No manager'</td>
<td>Numeric</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Q30.0</td>
<td>Q32.0</td>
<td>Q40.0</td>
<td>Company Depatment (Orgnivå 2)</td>
<td>String</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q31.0</td>
<td>Q33.0</td>
<td>Q41.0</td>
<td>Tjst 2</td>
<td>String</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q32.0</td>
<td>Q34.0</td>
<td>Q42.0</td>
<td>Tjst 3</td>
<td>String</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Q33.0</td>
<td>Q35.0</td>
<td>Q43.0</td>
<td>Blue- or White-Collar job</td>
<td>0 'BC'; 1 'WC'</td>
<td>Numeric</td>
<td>Nominal</td>
</tr>
<tr>
<td>Q34.0</td>
<td>Q36.0</td>
<td>Q44.0</td>
<td>Placeringsort</td>
<td>String</td>
<td>Nominal</td>
<td></td>
</tr>
</tbody>
</table>

* Question differs from S3

² 'Do not know' is possible response, coded as user-missing

³ 'Do not know / Not relevant' is possible response, coded as user-missing
**Addition of variables**

Using an area map of the campus it is determined that all buildings, except for building M are within geographical areas listed under Q10 for on-site-destinations. 94% of the responses given to the open question Q5 (Where is your main working location?) are identical to the names for the geographical areas provided under Q10. Adding M to the valid set of areas, the remaining 6% of the response to Q5 are recoded respectively as the area or as “Not On Site”. Accordingly, 8% of the respondents stated destinations beyond the listed options under Q10. Under closer inspection, 13 of these values are allocated to options within the response set, 19 are destination which are not on-site.

Adding further information based on the working location, dummy variables for the proximity to bus stops of the red, blue, yellow and purple Shuttle lines, and to the EBike stations are created. The dummy variables take the value one, if the stated working location is within 50 m of a CMaaS station providing the respective service.

As explained, the employee data set is treated similarly where applicable. Beyond, the variable WorkingLocation is added. It holds the same set of possible answers as the corresponding variable in Survey 3 (Q5), composed of the 13 areas from Q10 plus area M and the option “Not on Site”. Using the information provided about the building, 11,590 employees are successfully assigned to one of these areas, 511 are identified as “Not on Site”, while the working location of 71 employees cannot be assigned to either one of these options. Beyond, for 1,486 employees no information on the building is provided, which can consequently not be assigned to an area, but are instead recorded as “Missing”.
Annex 3: Descriptive Statistics

Age

As shown by Annex Figure 1 below, the respondents to survey 1, 2 and 3 adequately represent the overall distribution of employees, also with respect to mean and standard deviation. Survey 1 holds 4 invalid values for age and survey 2 holds 1. They are excluded from this figure.

Annex Figure 1: Age histograms for employees and respondents to survey 1, 2 and 3.

Correlations within Demographic Variables

Annex Table 4: Spearman’s rho correlation among socio-demographic variables from employees (N=15,658)

<table>
<thead>
<tr>
<th></th>
<th>Gender</th>
<th>Age</th>
<th>Manager Level</th>
<th>Blue- or White-Collar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>.035**</td>
<td>.023**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.007</td>
<td>.000</td>
</tr>
<tr>
<td>Age</td>
<td>Correlation Coefficient</td>
<td>.035**</td>
<td>1.000</td>
<td>-.090**</td>
</tr>
</tbody>
</table>


**. Correlation is significant at the 0.01 level (2-tailed).

Annex Table 2: Comparison of primary working location (areas) between surveys and all employees (N is indicated in the last row).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Survey 1 Count</th>
<th>Survey 1 %</th>
<th>Survey 2 Count</th>
<th>Survey 2 %</th>
<th>Survey 3 Count</th>
<th>Survey 3 %</th>
<th>Employees Count</th>
<th>Employees %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>125</td>
<td>29.9</td>
<td>110</td>
<td>32.8</td>
<td>130</td>
<td>31.9</td>
<td>2717</td>
<td>23.4</td>
</tr>
<tr>
<td>B</td>
<td>103</td>
<td>24.6</td>
<td>53</td>
<td>15.8</td>
<td>69</td>
<td>17.0</td>
<td>2557</td>
<td>22.1</td>
</tr>
<tr>
<td>C</td>
<td>41</td>
<td>9.8</td>
<td>28</td>
<td>8.4</td>
<td>27</td>
<td>6.6</td>
<td>1046</td>
<td>9.0</td>
</tr>
<tr>
<td>D</td>
<td>23</td>
<td>5.5</td>
<td>25</td>
<td>7.5</td>
<td>31</td>
<td>7.6</td>
<td>1037</td>
<td>8.9</td>
</tr>
<tr>
<td>E</td>
<td>28</td>
<td>6.7</td>
<td>30</td>
<td>9.0</td>
<td>40</td>
<td>9.8</td>
<td>944</td>
<td>8.1</td>
</tr>
<tr>
<td>F</td>
<td>22</td>
<td>5.3</td>
<td>22</td>
<td>6.6</td>
<td>25</td>
<td>6.1</td>
<td>914</td>
<td>7.9</td>
</tr>
<tr>
<td>G</td>
<td>22</td>
<td>5.3</td>
<td>25</td>
<td>7.5</td>
<td>29</td>
<td>7.1</td>
<td>658</td>
<td>5.7</td>
</tr>
<tr>
<td>H</td>
<td>7</td>
<td>1.7</td>
<td>3</td>
<td>.9</td>
<td>8</td>
<td>2.0</td>
<td>563</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Annex Figure 2: Percentage of driver's license holders by age, for survey 3 (N=422).

**Mobility related**

Regarding the sample sizes in Annex Table 5, the difference to the general sample sizes occurs since working areas which are not on-site, or in case of the employees’ records not reported. With respect to the percentages of respondents, bigger areas tend to be overrepresented, except for area B in survey 2 and 3.

Annex Table 5: Comparison of primary working location (areas) between surveys and all employees (N is indicated in the last row).
Based on the in Annex Figure 9 proportions of blue- and white-collar workers over the working location, the working locations can be clustered into three categories:

- **White-collar dominated**: at least 90% white-collar-worker
- **Mixed**: 10% to 50% blue-collar worker
- **Blue-collar dominated**: at least 50% blue-collar-worker

This grouping is implemented into the data for survey 3 on working locations and on-site destinations.

The in Annex Table 6 reported on-site destination results out of a multiple response question. Therefore, the percentages do not add up to 100% but represent how many respondents have mentioned the respective area as

---

**Annex Figure 3**: Blue- and white-collar proportions by working location. (Employees; \(N_{\text{total}}=11,590; N_{\text{min}}=N_{\text{Gröndal/Democenter}}=31\)
common destination. Also, the counts do not directly transfer to trips on-site but only as shares on the on-site trips. Both, the table about the working location (Annex Table 5) and the table on destinations are ranked according to the percentage in the last column. Even though the percentage themselves are not based on the same sample, comparing the ranking of the destinations by the occurrence, and working location by share, allows some interpretations. Area A being the location with the most employees, also attracts the most trips, while area B hosting a similar number of employees attracts far less trips. Area E, N and G are ranked much higher when it comes to destinations compared to working location.

Annex Table 6: Reported on-site destination to multiple response question (survey 3, Q5).

<table>
<thead>
<tr>
<th>On-Site Destination</th>
<th>Count</th>
<th>Column N %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>188</td>
<td>45.9%</td>
</tr>
<tr>
<td>E</td>
<td>142</td>
<td>34.6%</td>
</tr>
<tr>
<td>B</td>
<td>109</td>
<td>26.6%</td>
</tr>
<tr>
<td>G</td>
<td>71</td>
<td>17.3%</td>
</tr>
<tr>
<td>N</td>
<td>63</td>
<td>15.4%</td>
</tr>
<tr>
<td>C</td>
<td>49</td>
<td>12.0%</td>
</tr>
<tr>
<td>F</td>
<td>46</td>
<td>11.2%</td>
</tr>
<tr>
<td>D</td>
<td>46</td>
<td>11.2%</td>
</tr>
<tr>
<td>I</td>
<td>45</td>
<td>11.0%</td>
</tr>
<tr>
<td>J</td>
<td>42</td>
<td>10.2%</td>
</tr>
<tr>
<td>H</td>
<td>27</td>
<td>6.6%</td>
</tr>
<tr>
<td>K</td>
<td>26</td>
<td>6.3%</td>
</tr>
<tr>
<td>L</td>
<td>21</td>
<td>5.1%</td>
</tr>
<tr>
<td>Not On-Site</td>
<td>14</td>
<td>3.4%</td>
</tr>
<tr>
<td>Total</td>
<td>410</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Experience and Satisfaction with CMaaS

Below are the responses to all questions concerning experience and satisfaction with CMaaS on-site (Q15-34). 340 respondents in survey 3 have used Shuttle within the previous year (Q15) and answered the follow-up questions:
150 respondents of survey 3 have used the Taxi service within the previous year (Q20) and answered the follow-up questions:

Annex Figure 4: Experience and satisfaction with Shuttle (Survey 3, Q17-Q18, N=340)

Annex Figure 5: Experience and satisfaction with Taxi (Survey 3, Q21-Q23, N=150)
100 respondents of survey 3 have used the EBike service within the previous year (Q25) and answered the follow-up questions:

Annex Figure 6: Experience and satisfaction with EBike (Survey 3, Q26-Q27, N=100)

95 respondents of survey 3 have not used any entity of CMaaS within the previous year (Q29) and answered the follow-up questions:

Annex Figure 7: Reasons for not using CMaaS (Survey 3, Q30, N=95)
313 respondents of survey 3 have used some entity of CMaaS within the previous year (Q29) and answered the follow-up questions:

Annex Figure 8: Satisfaction and reasons for using CMaaS (Survey 3, Q32-Q33, N=313)
Annex 4: Results - Baseline

Comparison of original and weighted survey 3 sample to population (work force)

As shown through Annex Table 7 and Annex Figure 9 below, the weighting of blue-collar-workers by a factor of 3.829 has varied effects on the distributions of other socio-demographic variables. It increases the sample size of survey 3 from 422 to 569.0. The margin of female and manager of first order are closer to the population margins, while the other values reveal slightly increases in their differences to the population margins.

Annex Table 7: Comparison of original and weighted survey 3 sample margins of gender, manager level and blue- or white-collar workers to population.

<table>
<thead>
<tr>
<th>Variable and Value</th>
<th>Survey 3</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original Sample Margin</td>
<td>Weighted Sample Margin</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>female</td>
<td>32.5%</td>
<td>29.0%</td>
</tr>
<tr>
<td>Manager level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manager 2. order</td>
<td>1.4%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Manager 1. order</td>
<td>10.9%</td>
<td>8.1%</td>
</tr>
<tr>
<td>No manager</td>
<td>90.9%</td>
<td>87.7%</td>
</tr>
<tr>
<td>Blue- or White-Collar</td>
<td>12.3%</td>
<td>35.0%</td>
</tr>
</tbody>
</table>

The age distribution suffers from the weighting in so far as the local extrema at the age of 30 and 40 are amplified. The difference in mean also increases slightly from 0.45 to 0.65 years, while the standard deviation is closer to the population standard deviation. Overall, the improved representation of the employees through the weighting of blue-collar workers, outweighs the miner decreases with respect to other variables and is thus considered legitimate.
Blue-Collar worker

This part focuses on the on-site mode choices among blue-collar workers in the survey 3. Annex Table 8 shows, that the proportions which uses a certain mode differs largely between mobile and immobile respondents of this sample. The category of immobile respondents also includes the responses of 8 blue-collar workers, whose answers to Q9 (number of on-site trips per day) were originally Missing (Respondents: #32, #145, #148, #162, #172, #221, #396 and #398). But responses on on-site mode use (Q11) and destinations (Q10) are available for theses respondents. Therefore, Missing values are replaced by zero and are thus represented among the immobile sample. Except for two, all respondents checked at least one of the multiple response answers to Q10. Combining the responses, the blue-collar workers’ on-site destination choices reveal a big difference between stated mobile and immobile respondents. The same observation holds for on-site destinations among blue-collar workers.
Annex Table 8: Comparison of On-site mode choice among blue-collar workers (Survey 3; N_{bc}=52)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mobile On-Site No</th>
<th>Mobile On-Site Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Column N %</td>
</tr>
<tr>
<td>b) Taxi</td>
<td>1</td>
<td>2.7%</td>
</tr>
<tr>
<td>c) Shuttle</td>
<td>6</td>
<td>16.2%</td>
</tr>
<tr>
<td>d) EBikes</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>e) PT</td>
<td>1</td>
<td>2.7%</td>
</tr>
<tr>
<td>f) Bicycle</td>
<td>2</td>
<td>5.4%</td>
</tr>
<tr>
<td>g) Walking</td>
<td>10</td>
<td>27.0%</td>
</tr>
<tr>
<td>h) Car as driver</td>
<td>15</td>
<td>40.5%</td>
</tr>
<tr>
<td>i) Car as passenger</td>
<td>5</td>
<td>13.5%</td>
</tr>
<tr>
<td>j) Carsharing or</td>
<td>6</td>
<td>16.2%</td>
</tr>
<tr>
<td>department car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>k) Other modes</td>
<td>5</td>
<td>13.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>37</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Applied estimators for trip generation and distribution

**Trip Matrix**

Annex Table 9: Preliminary OD-Matrix

<table>
<thead>
<tr>
<th>Origin</th>
<th>A</th>
<th>E</th>
<th>G</th>
<th>K</th>
<th>I</th>
<th>J</th>
<th>F</th>
<th>D</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>593</td>
<td>401</td>
<td>116</td>
<td>45</td>
<td>86</td>
<td>91</td>
<td>118</td>
<td>104</td>
<td>123</td>
</tr>
<tr>
<td>E</td>
<td>206</td>
<td>139</td>
<td>40</td>
<td>16</td>
<td>30</td>
<td>32</td>
<td>41</td>
<td>36</td>
<td>43</td>
</tr>
<tr>
<td>G</td>
<td>144</td>
<td>97</td>
<td>28</td>
<td>11</td>
<td>21</td>
<td>22</td>
<td>29</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>K</td>
<td>15</td>
<td>14</td>
<td>16</td>
<td>3</td>
<td>21</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>I</td>
<td>43</td>
<td>40</td>
<td>45</td>
<td>9</td>
<td>59</td>
<td>11</td>
<td>6</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>J</td>
<td>30</td>
<td>28</td>
<td>31</td>
<td>6</td>
<td>41</td>
<td>7</td>
<td>4</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>F</td>
<td>199</td>
<td>135</td>
<td>39</td>
<td>15</td>
<td>29</td>
<td>31</td>
<td>40</td>
<td>35</td>
<td>41</td>
</tr>
<tr>
<td>D</td>
<td>231</td>
<td>128</td>
<td>41</td>
<td>27</td>
<td>93</td>
<td>155</td>
<td>131</td>
<td>27</td>
<td>301</td>
</tr>
<tr>
<td>C</td>
<td>96</td>
<td>91</td>
<td>101</td>
<td>20</td>
<td>133</td>
<td>24</td>
<td>13</td>
<td>35</td>
<td>17</td>
</tr>
</tbody>
</table>
Results of estimation for function on VKT over customers

The following two tables show the results of curve estimation for the modelling of the VKT through the number of customers for Shuttle (Annex Table 10) and Taxi (Annex Table 11).

Annex Table 10: Model summary and parameter estimates for Shuttle VKT by customer. (N=15)

<table>
<thead>
<tr>
<th>Equation</th>
<th>R Square</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
<th>Constant</th>
<th>b1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>.168</td>
<td>2.630</td>
<td>1</td>
<td>13</td>
<td>.129</td>
<td>2027.914</td>
<td>.715</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>.160</td>
<td>2.468</td>
<td>1</td>
<td>13</td>
<td>.140</td>
<td>-916.320</td>
<td>527.166</td>
</tr>
<tr>
<td>Power</td>
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<td>2.446</td>
<td>1</td>
<td>13</td>
<td>.142</td>
<td>621.202</td>
<td>.214</td>
</tr>
</tbody>
</table>

The independent variable is Shuttle customers per day.

Annex Table 11: Model summary and parameter estimates for Taxi VKT by customer. (N=15)

<table>
<thead>
<tr>
<th>Equation</th>
<th>R Square</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
<th>Constant</th>
<th>b1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
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<td>.072</td>
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<tr>
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<td>3.279</td>
<td>1</td>
<td>13</td>
<td>.093</td>
<td>65.341</td>
<td>.393</td>
</tr>
</tbody>
</table>

The independent variable is Taxi customers per day.