MASTERARBEIT / MASTER'S THESIS

Titel der Masterarbeit / Title of the Master's Thesis

Re-assembling mobility for automated public transport

Exploring the implementation of two semi-autonomous shuttle buses into the Seestadt quarter of Vienna as a practice of network building

verfasst von / submitted by

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angestrebter akademischer Grad / in partial fulfilment of the requirements for the degree of

Master of Arts (MA)

Wien, 2022 / Vienna 2022

Studienkennzahl lt. Studienblatt / degree programme code as it appears on the student record sheet:	UA 066 906
Studienrichtung lt. Studienblatt / degree programme as it appears on the student record sheet:	Masterstudium Science-Technology-Society
Betreut von / Supervisor:	Univ. Prof. Dr. Ulrike Felt

Acknowledgments

The contribution of colleagues, friends and relatives to this thesis cannot be overstated. I therefore want to thank all the people who supported me throughout the many months of conducting this study:

My parents who love and believe in me. They took care of my education early on and always lent the much-needed moral support.

My younger brother who worked on his thesis in parallel and provided me with eye-opening insights into the world of physics.

My wonderful partner with whom I shared similar struggles and who always stood up for me in times of crisis. Her work is a great inspiration to me.

My competent and kind supervisor who gave me valuable feedback and told me when to stop running in circles.

My teachers who introduced me to the field of Science & Technology Studies and accompanied my coming of age as a social science researcher.

My friends and colleagues who listened to my many complaints throughout the long and dark days of the pandemic and helped me get through this.

The participants of this study who shared their experiences without any form of compensation, making this study possible in the first place.

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1 Introduction

Figure I: These photographs show the actor who inspired this study and whose social relations I will analyze in detail: the Autonom Shuttle by NAVYA. Two of these autonomous minibuses were deployed in Vienna for the auto.Bus Seestadt research project. When not driving through the urban wilderness, they rested in their cozy garage.

1.1 AVs Honking in the November Cold

It took me a lot of time to get here. Google Maps predicted that I would ride my bike for 51 minutes or around 17 kilometers, but actually I arrived one and a half hours and a few breaks later. I have been here before, both physically and mentally, but it was not until quite recently that I knew what I would look for. Almost exactly a year ago, in November 2019, I rode the vehicles a few times and even did an interview with one of the operators for an assignment. In January 2020, after the first semester of studying Science and Technology Studies, my study group and I presented our final project on autonomous vehicles. The buses I encountered in Seestadt were only a side note, but the discussion afterwards raised so many questions that the topic stuck with me. Only a few months and the outbreak of a global pandemic later, I am now ready to start fieldwork here in Seestadt, on a drab November afternoon. For over a decade, the Wien 3420 aspern development AG has been building a city-within-a-city here. But from the perspective of my peers and me, it is far away from the heart of Vienna, and I know many that only know it by its name.

Figure II: Only one more turn to go from Aspern to Seestadt Aspern.

To get a sense of the distance and the location, I rode by bike to Seestadt. Starting at my home in the 10th district, I first biked to the Prater park, and from there over the Danube to the other side of Vienna. I continued my way in the 22nd district, Donaustadt, driving through the Stadlau quarter and then through Aspern. As I came closer to Seestadt Aspern, my surroundings began to look more and more suburban. Residential buildings gave way to single family houses. A guidepost told me to turn right, and after driving a small section through the countryside, I finally arrived at my destination. What did I encounter there? Large, state-of-the-art buildings held in natural tones, made of concrete, glass, steel, and wood. The artificial lake that lends Seestadt its name. A park surrounding the already finished center, and another, less idyllic belt of construction sites continuing to expand this proclaimed smart city development area. Beyond only lies the countryside.

Figure III: View from the terrace next to the metro station across the artificial lake to Seestadt's skyline.

What makes Seestadt smarter is not immediately apparent. It most definitely looks and feels nice, but after all, the local infrastructure is very similar to the rest of Vienna. Hopefully, I will encounter a mobility innovation today that could act as a flagship project of this smart city. I quickly ride to the U2 metro station, which connects Seestadt to the city center. I am now very close to my object of study, and at any moment expect to hear its honks howling through the November cold. Here, the auto.Bus Seestadt research project operates the very first autonomous vehicles of Vienna: two chubby little shuttle buses driving from the metro station to the center of the quarter and back. I am looking at the first stop right now. But I am not ready to catch a shuttle just yet. I first want to experience Seestadt, so I wander off into the direction of the Technology Center, which is another indicator for the innovative appeal of the district. How does the test operation of the autonomous buses fit into this narrative? How do the automated shuttles work in practice? On what infrastructures do they rely on and how did they end up here? I already have some clues, and I am determined to find out more.

1.2 Overview of the Research Project

Autonomous vehicles (AVs) are not a techno-futurist dream anymore, they are entering reality on closed test sites and public roads. Fully autonomous cars have been promised as being just around the corner since decades (Albert, 2019), but recent technological advancements led to a new hype and several practical applications made them accessible to consumers: Among others, the Google subsidiary Waymo currently operates a driverless ride-hailing service in Phoenix and San Francisco (Amadeo, 2021; Hawkins, 2019), and Tesla's Autopilot (n.d.) is an advanced driver assistance software (ADAS) promising an every-increasing degree of automation. There already have been fatal accidents involving AVs and ADAS (Maki & Sage, 2018; Shepardson, 2021; Stilgoe, 2018), which is an indicator that, for better or worse, the technology is slowly finding its way into reality. The rise of autonomous driving is accompanied by promises of great comfort for commuters: Hardware and software would replace human drivers. Your car would do the strenuous work of commuting for you, while being more efficient and safer than a human could ever be. The renewed interest in the technology is also linked to the crisis of automobility and the pressing societal issues linked to the worldwide dependence on cars (Albert, 2019). AVs are positioned as solution to our mobility problem while keeping car culture intact: "Here is a technology that promises to change the world without changing the world" (Stilgoe, 2019, p. 202). But the vision of a fully autonomous vehicle capable of matching the performance of humans, let alone surpass it, is yet to be fulfilled. According to optimistic predictions, this technology could still be made possible during the 2020s and become available as a luxury good during the 2030s (Litman, 2020, p. 28). The claim of autonomy itself is increasingly being criticized (Martínez-Díaz, Soriguera, & Pérez, 2019; Stayton, Cefkin, & Zhang, 2017; Tennant & Stilgoe, 2021), as automation technology will never be truly independent from human agency. Most of the academic discourse today focuses on automated driving, not autonomous driving, and conceptualizes AVs as vehicles that are equipped with an automated driving system (ADS), offering various levels of automation (SAE International, 2014; SAE International, 2021).

But how and to which purpose will AVs be integrated into mobility infrastructures and daily commutes? Besides augmenting privately owned analog cars, automated driving systems also bear potential for public transport, mobility as a service offerings, and freight transport. In contrast to private innovators less focused on infrastructural development and systemic changes, governments and policymakers are creating frameworks and concrete measures for implementing automation into society. Corresponding roadmaps and innovation programs exist both on the national and European level (ERTRAC Working Group

"Connectivity and Automated Driving", 2019; Ministry for Transport, Innovation and Technology, 2018). In Austria, the testing of AVs on public roads for certain use cases has been possible since 2016 (Legal Information System of the Republic of Austria, 2016). In light of the high and ongoing investments by both private innovators and public institutions, the uptake of automation technology in the mobility sector appears inevitable. Thus, the question is not whether AVs will become a widely shared reality, but how and under which terms and conditions (Stilgoe, 2019; Tennant & Stilgoe, 2021). These questions will also be decided on the local level. The city-state Vienna, which is the locus of this study, laid out its vision for sustainable development until 2050 (Vienna Municipal Administration, 2019). The future scenario for mobility and transport includes collectively used electric AVs as a supplementary option. Actually, automated transport will be implemented much earlier: The U5 metro line (wien.ORF.at, 2015), currently under construction, will be powered by the so-called X-Wagen, a fully automated train developed by Siemens (Siemens, 2018b; Wiener Linien, 2021c).

But the first AVs that operated in Vienna were two semi-autonomous shuttle buses. As part of the auto.Bus Seestadt research project (FFG Projektdatenbank, 2017), these vehicles drove on a fixed route through the newly built Seestadt quarter in the 22nd district Donaustadt from June 2019 to June 2021. The buses presented a temporary and experimental addition to the public transport infrastructure and were open to the public. To make the automation feasible, the AVs were supported by human operators who took over control when needed. Similar tests of autonomous minibuses have been conducted in other parts of Austria, Europe, and worldwide (Bloomberg Philanthropies & The Aspen Institute, 2019; Haider, Haydn, Klementschitz, Angerer, & Bauernfeind, 2017; pdcp GmbH, 2021; Salzburg Research, 2021). These operations present the first manifestations of automated driving in urban, suburban, and rural living contexts. In Vienna, the auto.Bus Seestadt project was pursued by a coalition of six partners: Wiener Linien as project leadership (2021b), the Austrian Institute of Technology (AIT) as scientific leadership (2019), the Kuratorium für Verkehrssicherheit (KFV) (2019), TÜV Austria, Siemens, and the French manufacturer NAVYA, which is one of the few companies offering automated minibuses as a finished product and service. The aim of the project was to optimize the operation for regular use in the future, gather practical experiences, and foster the public acceptance of AVs. The Ministry for Transport, Innovation and Technology provided funding through the Mobility of the Future Program (2012) and the Action Plan Automated Driving (2016).

This study explores how the project partners implemented the autonomous minibuses into Seestadt and how they coordinated the automation of public transport for this use case. I conceptualize the introduction of the two shuttle buses as the re-assembly of mobility, as existing infrastructures were rearranged and supplemented by digital sensors and datasets to integrate these new actors. From the perspective of Science and Technology Studies (STS), technological artifacts are both socially constructed and encompass politics by themselves (Akrich, 1992; Bijker & Pinch, 1987; Winner, 1986). Technology and society are thus deeply intertwined and have to be studied in relation to one another. In the case of the auto.Bus Seestadt project, the AVs, the stakeholders in the project, local infrastructures, and the community of Seestadt shaped and coproduced each other. Just as life in the quarter adapted to the new actors, the buses also had to adapt to the local conditions. I employ actor-network-theory (ANT) (Michael, 2017) as an analytical lens to study the test operation and the overarching research project as a network that associates human and non-human actors for the automation of public transport. This theoretical approach recognizes the agency of technological artifacts and infrastructures as a key contribution to the operation of the AVs. Another important aspect of the project is its location: Seestadt is one of the largest housing projects in Europe and a central building block of Vienna's urban development strategy. The district is presented as a smart city development area, as an "urban lab" and "city-within-a-city" (aspern. Die Seestadt Wiens, n.d.). Smart city technologies interweave the urban fabric with digital sensory infrastructures to enable various forms of automation and are usually accompanied by techno-utopian storytelling (Antenucchi, 2021; Gabrys, 2016; Graham, 2002; Söderström, Paasche, & Klauser, 2014). In this case, the testing of AVs and the creation of a smart infrastructural grid reinforced each other on a material as well as discursive level.

Instead of focusing solely on technical specifications or giving into stories of inevitable technological progress, STS research can help to understand the concrete conditions of automated driving. This study fills a gap in existing research by exploring the sociomaterial relations of automation for a specific case site. To reach the goal of this study, I pose the following main research question: *How did the project partners adapt the automation technology and the Seestadt quarter for the re-assembly of mobility?* Autonomous vehicles encompass a large variety of attachments and affordances (Tennant & Stilgoe, 2021) that have to be accounted for in the specific implementation. I want to understand which adaptations to the AVs and the urban infrastructures were necessary and how these changes contribute to the re-assembly of mobility in the district. To answer the research question, I conducted five qualitative interviews with one representative of the AIT, Wiener

Linien, the KFV, and the aspern.mobil LAB, as well as with one of the operators. In addition, I performed ethnographic fieldwork in Seestadt. I traced the infrastructural components of the test operation by foot and rode the buses many times, closely examining the interactions between ADS, the operator, and the environment. By doing so, I was able to grasp the relationship between the AVs and Seestadt as a seemingly ideal test environment.

After presenting the relevant strands of research on automated driving and its ramifications, both from STS and related fields, I elaborate on the main research question and the accompanying three subquestions. I then establish actor-network-theories and related approaches to the study of urban spaces and infrastructures as the employed sensitizing concepts. Next, I lay out the methodological approach to data collection and analysis. I then move on to the empirical findings, which are presented in pairs of detailed ethnographic narration and subsequent analytical reflection. These parts focus on the re-assembly of local infrastructures into the test operation, the chaining of actors for the automation of driving, as well as on key moments in the implementation process. Before offering my conclusions, I discuss the study's key findings along two central themes: the re-assembly of Seestadt into an ideal testing ground for automated driving and the tension between experimentation and the operation of a mobility service.

2 State of the Art

As a first step towards understanding the implementation of the two autonomous buses into Seestadt, I want to establish the state of the art of automated driving and its social relations. I start with a technical investigation of how the task of driving is being automated by building on studies outside STS, primarily from engineering. In the next step, I critically reflect on the claim of autonomy and the social context of automated driving. By drawing on social science and STS research, I ponder the question of how the agency of robotic vehicles can be conceptualized. In the second part of the state of the art, I explore the potential ramifications of implementing AVs into society: the politics of automated driving, the emergence of smart infrastructures and cities, their relationship to self-driving vehicles, issues of trust and safety, the governance of AVs with a focus on the European Union and Austria, as well as a short reflection on autonomous minibuses as a specific use case for automated driving technology. I relate the presented concepts and approaches to the case of the auto.Bus Seestadt project. This process helped me identify knowledge gaps this study contributes to and informed the conducted empirical research.

The operation in Seestadt has to be understood in the context of the recent hype surrounding AVs, whose development gained traction over the past decade. While the term 'autonomous vehicles' applies to all forms of vehicles offering automated driving functions, the public discourse predominantly revolves around the prospect of self-driving passenger cars. IT companies like Uber, Tesla, and Google, as well as traditional manufacturers like GM and Audi are working towards this vision, positioning AVs as a replacement for privately owned cars and for commercial fleets. There is the conviction that cars will inevitably become autonomous, that market-driven technological advances will make this development possible, and that a working product is just around the corner. As Albert (2019) aptly describes for the US-American context, the hype surrounding AVs is related to the latest crisis of automobility: Despite having enabled the mobility of the masses and economic prosperity, societies today face the problematic consequences of their reliance on cars. Individual transport and the sheer number of vehicles lead to congestion, smog, noise, deadly accidents, urban sprawl, and large amounts of greenhouse gas emissions around the globe. A new kind of vehicle is presented as the solution: "In the face of climate change, we're not abandoning our cars; we're electrifying them. Likewise, the driverless car will revolutionize automobility to allow it to thrive for another century" (Albert, 2019, p. 7). While many arguments for adopting electric AVs focus potential efficiency gains, safety improvements, and ecological benefits, the discourse also speaks to a futuristic dream of comfort: "You would climb in, push a button, and go. Technology would make car travel far safer and more relaxing than it had ever been" (Albert, 2019, p. 245). Simply put, the self-driving car would free drivers from their dull responsibilities while still offering all liberties of individual transport.

But the existence of such a vehicle will remain a dream for the near future, despite all marketing claims. Even though there are predictions that AVs offering full automation under most circumstances might be technologically possible during the 2020s, this is a highly optimistic scenario dependent on rapid technological advances (Litman, 2020). Even if it would be possible, these products would probably remain a low volume luxury good for a few selected individuals. But as the test operation in Seestadt showed, the automation of driving is not only limited to the consumer market. Before making up a significant portion of private car ownership, AVs will probably become part of commercial fleets operating in strongly delimited areas, like certain city quarters or university campuses (Yurtsever, Lambert, Carballo, & Takeda, 2020). This way, the high costs and limitations of the technology could be mitigated to some degree. The test operation in Seestadt was a first step in this direction. It also highlights that, besides private companies, the public sector is a major stakeholder and innovator in automated transport.

2.1 Constructing the Robotic Car

If AVs will revolutionize automobility and form the next generation of cars, what differentiates a conventional car from an autonomous vehicle? According to Thrun's (2010) conceptualization, a self-driving car is a conventional automotive with an integrated robotic system. This system would replace a human driver to varying degrees, depending on how advanced the system is. There are three main functions that are being automated: perception, planning, and control. These can be differentiated further, and only the control of the vehicle is trivial at this point. Achieving the complete automation of driving could make the human driver obsolete, which is the utopian vision underlying most discourses on AVs. The following technical investigation will primarily focus on passenger cars as the most prominent use case, but the introduced terms and concepts apply to any other autonomous ground vehicle.

Despite the recent push towards automation, self-driving cars have been envisioned for a long time, as Albert (2019) notes: In 1939, GM presented its vision of highways with integrated cables for vehicle automation at the World's Fair. The idea was picked up again in the 1950s with a working prototype and the Firebird I-III concept cars. In 1994, the engineer Ernst Dickmanns and his team operated a small fleet of customized vehicles automatically on highways as part of the pan-European PROMETHEUS project (Delcker, 2018; Dickmanns, 2002; Dickmanns & Asaro, 2010). The automation was powered by a novel technique for recognizing the edges of roads and vehicles, which outperformed all other solutions at that time. Even though human drivers had their hands on the wheel and the technology was limited to highways, this experiment presented one of the first successful tests of robotic cars under real-world conditions. In 1997, there was a demo of eight cars driving automatically on a section of the Interstate 15 in San Diego. This "hands-off, feet-off" (Albert, 2019, p. 252) approach to automated driving depended on magnets embedded in the road, as well as radar and radio connection between the vehicles. However, there was no interest in making the necessary infrastructural investments.

In the early 2000s, the research and development of AVs gained traction through a series of events: In 2004 and 2005, the US Defense Advanced Research Projects Agency (DARPA) hosted the first of the so-called Grand Challenges, which were races between AV prototypes on desert trails. Different teams competed for prize money employing state-of-the-art technology. As Albert stresses, the general approach to automation had changed:

> The military needed go-anywhere machines that could operate in traffic or off-road, in places where the rule of law held firm and in lawless war zones. "Hand-off, feet-off" driving would not be enough. "Driverless," "autonomous," "robot" cars, that was the thing. (Albert, 2019, p. 254)

While in 2004 not a single vehicle finished the race, in 2005 there were already five finalists. The 2007 Urban Challenge significantly increased the difficulty, as the AVs had to operate a city-like test environment while adhering to traffic regulations. Six teams completed the challenge.

Since then, several private companies have been investing in the field and received heightened public attention. A comprehensive overview of testing activities by both private and public actors is beyond the scope of this study, but corresponding resources already exist (Bloomberg Philanthropies & The Aspen Institute, 2019). I only want to give a few examples: In 2009, Google started working on an autonomous vehicle. Sebastian Thrun, whose team from Stanford University won the DARPA Challenge in 2005 and came in second in 2007, took on a leading role (Harris, 2014). Later, the Google car project became the company Waymo, which today operates an AV ride-hailing service in selected areas of Phoenix and San Francisco (Amadeo, 2021; Hawkins, 2019). In 2015, Tesla released its Autopilot driver assistance software to consumers (Tesla, 2015). Ever since its release, it has been accompanied by false claims and misconceptions regarding its self-driving capabilities. The use of the autopilot feature was repeatedly linked to fatal accidents over the years, which are under investigation by the US National Highway Traffic Safety Administration (NHTSA) (2021; Shepardson, 2021). In 2016, Uber started testing an AV fleet in Pittsburgh (All Things Considered, 2018). Later, the test program was paused after the killing of Elaine Herzberg by one of the employed vehicles in Tempe, Arizona (Maki & Sage, 2018). NAVYA (2021), the French company who provided the shuttle buses for the auto.Bus project, has been producing automated minibuses since 2016 and claims to have sold around 180 units to customers around the world. As an increasing number of AV prototypes and products entered the road, the public perception of automated driving changed accordingly: The dream of the driverless car yet again seems just around the corner, even if it might lie multiple decades in the future.

2.1.1 Automating the Task of Driving

Despite the bold claims by companies and institutions working on AVs and the general hype surrounding the technology, there is no vehicle capable of operating on public roads fully automatically. All current implementations are limited, which relates to how driving is approached from an engineering standpoint: A review of current AV technology notes that the employed robotic systems “divide the massive task of automated driving into subcategories and employ an array of sensors and algorithms on various modules” (Yurtsever, Lambert, Carballo, & Takeda, 2020, p. 2). This way, the various subtasks, like perception and path planning, can be tackled independently using research from established scientific fields, among them robotics and computer vision. As the complete automation of driving is currently out of reach, systems afford different feature sets and limitations depending on how and whether certain driving tasks are resolved.

In order to measure how advanced a system is and to make it comparable to others, there are different scales for differentiating the degree of automation into multiple levels. The US-American standards developing organization Society of Automotive Engineers (SAE) International has been working on a taxonomy for automated driving systems since 2014, with the most recent revision published in April 2021 (2014; 2021). This work serves as the common ground among most actors working in the field. Even though the approach of the SAE is being criticized for its normative implications (Stayton & Stilgoe, 2020), and despite the existence of alternative approaches (Fridman, 2018; Gasser et al., 2013), the established standards still provide a detailed vocabulary for describing the functions of robotic cars and the interaction between humans and machines. I present the most important terms and concepts while also pointing out the lacks and limits of this framework.

Instead of using terms like “autonomous vehicle” or “self-driving,” the SAE speaks of ‘Automated Driving Systems’ that perform a ‘Dynamic Driving Task’ (DDT) on a sustained basis by fulfilling a variety of subtasks: controlling the vehicle, monitoring the environment, and supervising the driving performance (Martínez-Díaz et al., 2019; SAE International, 2021). The taxonomy differentiates between six levels of automation, ranging from level zero – ‘No Driving Automation’ – to level five – ‘Full Driving Automation’. The automation level of a given technology depends on which subtasks are performed by the ADS and which by a human actor. Active safety systems or driver assistance systems, like lane keeping assistance, are not covered by these levels, as they only present a momentary intervention into the driver’s action. Currently, only partial implementations of level three automation exist (Martínez-Díaz et al., 2019). Level three – described as 'Conditional Driving Automation' – means that an ADS can perform the driving task in the context it is specifically designed for. But such systems still rely on a human driver[1] overseeing the operation. The human agent needs to take over control if requested by the ADS or if the ADS fails. Thus, the current state of the art of autonomous vehicles is defined by human exceptions to the general rule of automation. The SAE taxonomy enabled me to systematically describe the functions and limitations of the vehicles used for the auto.Bus Seestadt project.

In order to analyze the limitations of the shuttle buses, it is also necessary to have a basic understanding of how AVs work on a technological level. Approaches to automated driving can be differentiated according to their connectivity and algorithmic design (Yurtsever, Lambert, Carballo, & Takeda, 2020). Ego-only ADSs perform all tasks themselves, so every vehicle is equipped with the necessary hardware and software components for doing so. In contrast, connected systems would distribute and coordinate information as well as tasks across a network of vehicles and infrastructures. While such a networked approach could lead to great efficiency gains, there currently is no working system yet. With reference to Albert (2019), AVs today are mostly imagined as solitary actors independent of supportive infrastructure. These ego-only systems follow a modular design, which employs a pipeline of different subsystems for "feeding raw sensor inputs to localization and object detection modules, followed by scene prediction and decision making" (Yurtsever, Lambert, Carballo, & Takeda, 2020, p. 4). As reflected by Martínez-Díaz et al. (2019), the modular design mimics the human decision-making process, or at least how it is being imagined by engineers. Another approach is end-to-end driving, which directly translates sensor data into driving actions using machine learning algorithms. While there currently is no fully functional prototype yet, end-to-end driving could overcome the architectural complexity of modular systems in the future.

A key feature of AVs is 'Object and Event Detection and Response' (OEDR), which allows the ADS to react dynamically to traffic conditions and other road users. OEDR is a requirement for level three automation and above (SAE International, 2021). The shuttle buses used for the auto.Bus project are capable of such functions. In marketing material on the Autonom Shuttle model, NAVYA claims that its hardware and software components "allow vehicles to locate and analyze the environment," so that they can "make the best

1. The taxonomy of the SAE differentiates between users of the technology, users who could act as drivers, and drivers. For the sake of simplicity, I will address the person who is expected to take over control from the ADS interchangeably as user and driver.

decisions without a driver" (2020, p. 10). As the results of this study show, automated responses by the buses are largely limited to stopping. In order to provide the data needed for OEDR, AVs are equipped with a multitude of sensors. As different sensors collect different types of data, a combination of technologies is being used, among them: radar, sonar, LiDAR (a spinning laser), cameras, GPS, and proprioceptive sensors like wheel encoders, inertial measurement units (IMU), tachometers, and altimeters (Martínez-Díaz et al., 2019; Yurtsever, Lambert, Carballo, & Takeda, 2020). The perceptive capabilities of humans serve as the baseline for measuring the OEDR performance of an ADS. A comparison of human senses and technological systems finds that, while in theory an automatic system could perform better than a human driver, the overall performance of humans is hard to match (Schoettle, 2017). To come even close to this baseline, the data from different sensors gets combined through a process called sensor fusion. The idea is to overcome the weaknesses of the individual sensors while playing on their strengths. A precondition for OEDR and the automation of driving is the ability of the vehicle to localize itself relative to the environment. The greatest challenges for localization are precision and resource-intensity. A combination of GPS and IMU yields far too imprecise results, which in the case of NAVYA's automated driving solutions is mitigated through a technique called Multi-GNSS Real-time Kinematics (RTK) (Sun, Xia, Foster, Falkmer, & Lee, 2017). By adding a local reference antenna to the environment, GPS errors can be significantly reduced (Rehrl & Zankl, 2018). In addition, the Autonom Shuttle employs point cloud matching (Yurtsever, Lambert, Carballo, & Takeda, 2020), which is a priori map-based localization technique. Based on the data stemming from the LiDAR sensors on top of the vehicle, the ADS creates a point cloud map in real time and compares it to a pre-recorded and manually edited map of the environment (Levinson, Montemerlo, & Thrun, 2008). As will be shown in the analysis, this method encompasses two major disadvantages: The buses could only drive along the pre-recorded route and any major changes in the environment made the automation impossible.

While a complete technical discussion of automated driving systems is beyond the scope of this study, I want to elaborate on two limitations of level three automated driving systems especially relevant to my case: A key factor is the 'Operational Design Domain' (ODD) of an ADS and its automation features. The ODD describes the context in which a feature is designed to work (SAE International, 2021). The ODD can be defined by a variety of parameters, among them speed, location, the type of road, traffic conditions, and weather. A level five ADS would offer an almost unrestricted ODD, but as it is currently unattainable, all AVs depend on a strictly defined ODD to achieve stable automation. Identifying the ODD of the shuttle buses is an important question I explore in the analysis. In this case, the ODD of the shuttles corresponded to the design of the test operation and the employed infrastructure. The restriction of the operation to a single route already hinted towards a narrowly defined ODD.

Furthermore, AVs up to level three automation depend on the actions of a human driver throughout operation. As part of the so-called ‘Dynamic Driving Task Fallback’ (DDT fallback), the ‘Fallback-Ready User’ has to take over control from the automation system (SAE International, 2021). A DDT fallback either occurs because the ADS cannot resolve an imminent traffic situation, or because the vehicle leaves its ODD. The transfer of responsibilities between human and machine, which is often called the handover situation, is mediated by the human-machine interface (HMI) of the ADS and proves to be challenging: “The user and the ADS need to have a mutual understanding, otherwise, they will not be able to grasp each other’s intentions. The transition from manual to automated driving and vice versa is prone to fail in the state-of-the-art” (Yurtsever, Lambert, Carballo, & Takeda, 2020, p. 19). In the case of the auto.Bus project, the human operators were central to the safety and feasibility of the operation. I will analyze the interaction between the operator and the ADS in more detail in the empirical section.

The problematization of human-machine relations can be related to how automated driving technology is framed and understood. While the taxonomy of the SAE aims at being descriptive, Stayton and Stilgoe (2020) point out that it nevertheless configured the public discourse on AVs in a normative way: “It has served to reinforce some myths of autonomy: that automation increases linearly, directly displaces human work, and will continue until automation is total and humans are completely eliminated from the system” (2020, p. 14). The authors diagnose a fixation on the highest possible level of automation among policymakers and innovators, while real-world applications of automated driving bring to light the technology’s dependence on humans, data, infrastructures, and a strongly delimited ODD. Rather than focusing on the level of automation, societies should discuss the conditions for automated driving. Defining clearly delimited use cases for AVs might prove more efficient and practical than hoping for an autonomous jack of all trades. Fridman (2018) proposes an alternative, human-centered approach to the abstract distinction of automation levels. He only differentiates between shared autonomy and full autonomy, thus simplifying the complex differentiation of automation levels. The goal of this simplification is to shift attention from the currently unattainable goal of full automation to the optimal cooperation between the ADS and a human driver.

After having established the technical aspects of automated driving technologies, I will elaborate on the claims of autonomy and automation in the next subchapter. Building on insights from Science and Technology Studies, I approach these issues through the concept of agency. How is the agency of driving machines organized in practice and how does it relate to human actors like the driver or the operator inside the AV?

2.1.2 Conceptualizing Agency in Automated Driving

A closer technical examination revealed that the automation of driving is a relative process and not an absolute result. The SAE taxonomy (2021) explicitly advises against commonly used terms like "autonomous vehicles," "self-driving" or "unmanned," as they create the impression that ADSs would be able to drive independently under all circumstances without the need for human intervention.[2] The attribute "autonomous" seems to be the root of this misconception, as it ascribes a level of agency and independence to the technology similar to that of a human. Even if there would be an AV offering full automation, according to the SAE, labeling it "autonomous" would still contradict the system's lack of free will:

> Additionally, in jurisprudence, autonomy refers to the capacity for self-governance. In this sense, also, "autonomous" is a misnomer as applied to automated driving technology, because even the most advanced ADSs are not "self-governing." Rather, ADSs operate based on algorithms and otherwise obey the commands of users. (SAE International, 2021, p. 34)

Rather than calling automated driving systems autonomous, they should be described as cooperative. After all, the technology depends on the constant interaction between the elements of its modular architecture, technologies outside itself, like GPS or smart infrastructures, and human beings, like the fallback-ready user.

The previously mentioned DDT fallback, or handover, is the most apparent case for the interdependence of humans and machines in automated driving. McCall et al. (2019) developed a taxonomy of handover situations that extends existing standards regarding the distribution of responsibility and liability between the ADS and the driver. They differentiate between scheduled and non-scheduled handovers, between the driver and the system as the initiator of the handover, and the timing as an additional factor. Scheduled handovers are limited to fallbacks that are planned long before the situation arises, like when the ADS would leave its ODD at a certain distance. Non-scheduled

2. Despite the ambiguity of such terms, I will continue to use the full palette of names and attributes to describe the technology that they reference: a vehicle equipped with an ADS.

system-initiated handovers arise spontaneously during the DDT if the ADS reaches its operational limit, e.g. because of a difficult traffic situation. At level three automation, the user is expected to be fallback-ready when prompted, but the driver still has a short amount of time to take over control. Non-scheduled emergency handovers are instances in which the system cannot operate safely anymore without sufficient prior warning, either as recognized by the ADS or by the driver. The system is expected to stop itself safely when encountering such a failure.

This conceptual analysis of handover situations presents two major difficulties regarding the autonomy of AVs and their cooperation with human users: In the case of a level three ADS, the system is expected to monitor and react to the environment, so the user might not be aware of imminent dangers. Nevertheless, the user is expected to take over control quickly after being prompted, but only if the system is sure that the driver is able to do so. However, gaining full awareness of both the situation and the system after a period of inactivity is challenging. How these interdependences can be organized safely and reliably, and how liability can be attributed in the case of failure, remains problematic. In addition, “the responsibility for having knowledge of the system capabilities rests with the driver and is not likely to fully change in this regard” (McCall et al., 2019, p. 517). Thus, AVs offering less than level five automation neither free users from the task of driving, nor from their responsibilities. Even at level five, automated driving systems would not be autonomous, but would still need to cooperate with human users.

With reference to Yurtsever et al. (2020, p. 19), the cooperation and distribution of responsibilities between the ADS and the user presents a major challenge for the HMI of automated driving systems. Wolf (2016) discusses the operational design of human-machine interactions from the perspective of cognitive psychology. He argues that humans currently lack the appropriate mental models for making sense of automated driving functions, leading to distrust in the system, lack of awareness, and the deterioration of driving skills. Thus, AVs suffer from the irony of automation described by Bainbridge (1983): The ADS is imagined to take over driving from the error-prone human individual, but at the same time, the allegedly unreliable human subject is responsible for monitoring the operation of the machine and take over in case of failure. This paradox shows that the framing of human agency as deficient and the idea of replacing drivers with technology are ill advised: users have to act as drivers and supervisors at the same time. Without human intervention, no ADS would be able to function.

In a similar vein, Stilgoe (2018) criticizes the way AVs are presented in most public discourse: “Autonomous vehicles are not self-contained, they are not self-sufficient and they are not self-taught” (2018, p. 35). Private innovators would exploit such claims to justify their authority over how the technology is regulated, implemented, and used. The claim of autonomy is especially prominent in the context of machine-learning algorithms employed for ADSs, which are presented as being superior to human sensory capabilities and reflexes. Instead of conceptualizing human agency as deficient and regulation as a barrier to innovation, Stilgoe argues that processes of social learning will be essential for realizing the technology in a sustainable and equitable manner. In their ethnographic study on a simulated driving environment, Stayton, Cefkin, and Zhang (2017) underline the complex interdependence of AVs and human drivers. The authors argue that autonomy is multiple and polysemic: “One may be freed from certain tasks but also further embedded in sociotechnical systems that are beyond individual control” (2017, p. 93). AVs increasingly depend on networked technologies, so that “these vehicles will never be able to be unplugged” (2017, p. 99). Furthermore, the idea of progressively replacing human drivers with automated system ignores that driving is not only a technical function but also a social practice: It encompasses the negotiation of trust, responsibility, and various forms of mobility. Automated vehicles take part in these interactions while complicating matters through additional variables. These machines should therefore be regarded as sociomaterial instead of solely technological.

When taking these insights into account, the implementation of the autonomous shuttle buses into Seestadt was determined by the interdependences of the automation system and the way these affordances were organized. Rather than simplifying matters, the automation of public transport poses new challenges for the relationship between vehicles, passengers, drivers, and infrastructures. The agency of technology and its social embedding are prominent topics in STS research. Actor-network-theory is a school of thought founded on the principle that the human and the non-human, as well as nature and culture, should not be separated on an analytical level. By dissolving such dominant dichotomies, proponents like Latour (2005) tried to expand the object of social sciences beyond the issue of human relations. He questioned what counts as the social in the first place: “The social has never explained anything; the social has to be explained instead” (2005, p. 97). I expand on ANT as the sensitizing concepts of this study in chapter four, but I briefly want to argue the relevance of selected works for my project here.

Michael (2017) gives a systematic overview of how ANT developed as a theoretical approach since the 1980s. He traces ANT works through three phases: classical ANT studies that established the most prominent concepts and vocabulary, the translation of ANTs to other disciplines, as well as the proliferation of ANT thinking by Post-ANT approaches. I primarily employ studies from the classical phase for exploring the implementation of the test operation into Seestadt. Callon and Latour (1981) build upon Hobbes' concept of the Leviathan as the absolute sovereign of society to pose a central question of the social science research: "How does a micro-actor become a macro-actor?" (1981, p. 279) They argue that the differentiation between the micro and the macro level of analysis does not hold. To them, a macro-actor is a micro-actor that has grown in size by translating many other actors and by fortifying the social bonds binding them to their designated place in the network. The process of translation is a key sensitizing concept of this study, as it allowed me to analyze how the project partners interested others in joining the research project and how they coordinated the actions between heterogenous actors for the automation of driving. Callon's (1986b) study of the failed development of the véhicule électrique in France during the 1970s is especially relevant to my case. He uses ANT for analyzing the implementation of a new type of automobile into society. Callon shows that the political and economic interests of institutions and companies, engineering problems, and the behavior of non-human actors like fuel cells were all part of this actor-network. Thus, I relate the technological challenges of implementing the autonomous shuttles into Seestadt to the social and political aspects of the research project. In his other well-known ANT study on the scallops and fishermen of St Brieuc Bay, Callon (1986a) describes the various steps of network building in more detail. There are similarities between the group of scientists trying to preserve the livestock of scallops and the alliance of project partners working on the implementation of the test operation into Seestadt. In both cases, the network builders adapted an existing technology to the local conditions by convincing human- and non-human actors of serving certain roles in the network. The notion of arenas of development (Jørgensen & Sørensen, 1999) provides an analytical tool for conceptualizing both competition and co-operation between different actors during the development of a new technology, positioning it as a supplement to ANT. The concept directs attention to the different areas of expertise and interests among the project partners. When interpreting the test operation and research project as problem arena, it appears as the space where the interests of the allied organizations overlapped.

As previously argued, automated driving systems depend on the cooperation between the different software and hardware components, as well as between the technological system and the human user. How these interactions should be organized is being discussed controversially, but there is the general conviction that actors on the production and policy side determine the behavior of both the technology and the end users. Contrary to this form of social constructivism, certain features and affordances of AVs appear as inevitable and outside of any social control. ANT challenges both technological determinism and social constructivism by attributing agency to human and non-human actors alike. Akrich (1992; Akrich & Latour, 1992) proposes a theoretical framework for analyzing the construction and use of technical objects based on the notion of inscription. How a technology is being used is determined in part by the norms and ideals inscribed into it by the developers. Users might deviate from these pre-scriptions by enacting their own sets of de-scriptions. Thus, technology is not limited to self-contained artifacts and authoritative instructions but emerges from the interactions between heterogenous actors.

Latour (Johnson, 1988; 1992) explores the role of non-humans in human society through a variety of seemingly mundane artifacts like the door closer, the hotel room key, and the seatbelt. In each of those cases, tasks are delegated from a human to a non-human actor. It might perform these duties more reliably, but also enforce its own sets of affordances. The reliance of society on non-human actors is an important point of reflection for the case of automated driving, which heavily draws from the idea of delegating more and more driving tasks from the driver to the ADS. As Latour's case studies show, depending on non-humans always encompasses moral decisions and forms of discrimination. In the analysis, I will explore the distribution of tasks among the ADS of the shuttle buses and the human operators, as well as the limitations of this delegation. While the concept of the network intuitively fits the modular architecture of ADSs and the complex arrangement of the test operation, ANT is not limited to networks in the technological sense. Latour (1996; 1999) clarifies common misconceptions regarding the theoretical assumptions and principles of actor-network-theory. He highlights that ANT is primarily interested in the social relations between heterogenous actors, as well as diverse forms of agency. Thus, I will focus on the social dimension of automation rather than its technical specifications.

2.2 Bringing Automated Vehicles on the Road

The examination of the technical aspects of automated vehicles revealed that all current solutions are defined by profound limitations. Regardless of the level of automation, these systems depend on the cooperation between human and non-human actors, like human drivers, sensors, and algorithms. Therefore, automated driving is not only a technological problem, but a sociotechnical one. In the second part of the state of the art, I reflect on the process of implementing AVs into society. Tests by private companies and publicly funded research projects, like the auto.Bus Seestadt project, are the first attempts at bringing AVs onto actual roads. They provide the opportunity for a critical reflection of how the vision of automated transport is being realized.

In order to understand the societal context of the test operation in Seestadt and account for its material impact on the district, I introduce additional strands of literature: I start by reflecting on the political implications of automated driving technology. Next, I present research on safety concerns and the acceptance of AVs while questioning dominant narratives in the current discourse. As AVs are bound to their context of use and the availability of digital data, sensors, and network connections, I then introduce research on urban infrastructures and smart cities to make sense of these relationships. I conclude with an overview of policies and governance approaches to automated driving in the European and Austrian context. This section also includes resources on the development and testing of autonomous minibuses, which are especially relevant to this study.

2.2.1 The Politics of Automated Driving

The potential benefits of adopting AVs are manifold (Martínez-Díaz et al., 2019) and range from economic growth, sustainability, and accessibility to safety and efficiency gains. Most of these benefits are contrasted by significant risks and drawbacks, among them the potential increase in vehicle ownership and traffic, energy consumption and e-waste, as well as potentially deadly technical malfunctions and cyberattacks. A discussion of potential ramifications would span multiple scientific fields and is beyond the scope of this project, but the basis of many prominent arguments should be critically reflected: The current discourse largely revolves around what-if scenarios and predictions with very little ground truth. Simulating the effects of something that does not exist yet is hard, and the results are largely limited to thought experiments. For example, a relatively popular study (Bischoff & Maciejewski, 2016) used a computer model to test the replacement of conventional private cars driving inside Berlin with fully autonomous robo-taxis. The results are striking: A fleet of 90.000 to 110.000 AVs could meet the demand normally served by 1.1 million cars. What might seem like a strong argument for the development and large-scale deployment of self-driving taxis is actually science-fiction: Of course, fully autonomous taxis available to all would dwarf any current form of individual transport, but the existence of such an ultimate vehicle fleet is out of reach.

The reality of automated driving is much more conflicted, as Stilgoe (2019) points out: Innovators like Nvidia or Google promise to revolutionize mobility by replacing human drivers with ever more advanced machine learning algorithms, but automobility itself remains unquestioned. This story of disruption without change does not hold, as "cars are only part of a much larger sociotechnical system. For self-driving cars to work, the world around them will indeed need to change" (2019, p. 202). Instead of giving into the race for autonomy, the societal discourse should focus on the conditions under which AVs will operate. A discussion of the politics of automated transport needs to take place: Who will benefit from this technology and how do societies need to adapt? These questions also informed the analysis of the auto.Bus Seestadt project. By exploring a concrete implementation, this study contributes to filling a gap in STS research regarding the practical implications of automated driving technology.

Studying the relations between politics and technology has a long tradition in STS. Bijker and Pinch (1987) combine different approaches to social constructivism for studying innovation and the evolution of technological artifacts like the bicycle. Their multidirectional model links different variations of a technology to the problems of relevant social groups. Over time, certain variants get stabilized, either by closing open problems on the rhetorical level or by redefining them. This approach can be translated to the case of AVs, as the technology is still very open regarding its form and function. At the same time, certain variants dominate the discourse, like private cars used for ride-hailing services operated by private companies, or minibuses used by publicly funded research like the auto.Bus Seestadt project. In contrast, Winner (1986) insists that technological artifacts cannot be reduced to their social determination and context of use. Instead, material objects and technological arrangements would enforce certain political orders by themselves. The motivations of some private companies for investing into AVs already underline this point: Uber believes in the potential of getting rid of its already underpaid human drivers by replacing them with software in the future (Albert, 2019). To some degree, the devaluation of human labor seems to be inscribed into the technology, even if this potential might never be fully realized. Regarding the adoption of new technology, Winner conceptualizes two sets of leading questions that can be translated to the case of automated driving: While the first one revolves around the binary choice of moving forward with the development of a technology or not, the second one "has to do with specific features in the design or arrangement of a technical system" (Winner, 1986, p. 28). Even though the adoption of AVs seems inevitable at this point, their final form is still up to debate. The public test operation in Seestadt holds insights regarding the specific qualities of the technology in the context of public transport.

Tennant and Stilgoe (2021) build upon prior approaches to the study of technology for conceptualizing the attachments of autonomous vehicles. Attachments here describe the requirements, limitations, and effects of automated driving systems, as well as the complex configuration of different forms of autonomy and the way the technology is being used. The authors relate different layers of attachments used by stakeholders for making sense of the technology to three different strategies used by developers for managing the attachments of self-driving vehicles in practice. Tennant and Stilgoe conclude that the general claim of autonomy hinders the discussion of the conditions for automated transport. Summarizing the whole sociotechnical dilemma of governing AVs, they point out the fallacies of the current debate:

> The sequence goes: first solve the technical problem (get the artificial intelligence to work), then think about the rest. But the technology will not 'work' without considering its attachments. And, behind the scenes, developers are frantically seeking to make sense of the attachments that they privately know will define their futures. (2021, p. 18)

Instead of ignoring the political implications of such attachments, they should be at the center of governance approaches and forms of public deliberation. The cooperation of different partners for the auto.Bus Seestadt research project and the design of the test operation present an interesting case of how the attachments of the autonomous shuttle buses can be handled. As the analysis shows, a number of compromises had to be made to accommodate the affordances of the technology.

2.2.2 Acceptance and Safety

While the conditions for autonomous vehicles are not discussed sufficiently, the issues of acceptance, trust, and safety feature prominently in the public discourse. With reference to the dream of freeing drivers from the task of driving (Albert, 2019), there is the conviction that consumers would be in favor of adopting AVs as the ultimate mobility machine. At the same time, policymakers and private stakeholders alike fear the public's potential lack of acceptance. Thus, problematizing acceptance and making surveys for different contexts and demographics has become a popular endeavor in research on automated driving.

According to a study in the German context (Hampel, Kropp, & Zwick, 2018), only 16% of participants would hand over control to an autonomous car and a majority of 56% thinks that such a vehicle would not correspond with their preferred way of driving. These doubts appear to be linked to safety concerns and the lack of an actual driving experience. For the US-American context, the lobbying organization Partnership for Automated Vehicle Education (PAVE) commissioned a poll that presents similar public concerns: Of all participants, 48% “would never get in a taxi or ride-share vehicle that was being driven autonomously” (2020, p. 1). Findings like these are used to underpin the imaginary of ignorant publics hindering the adoption of AVs (Tennant & Stilgoe, 2021).

How stakeholders like policy experts imagine the users of AV was studied using sociotechnical imaginaries as an analytical lens (Graf & Sonnberger, 2020). The results show that imaginations of users are heavily influenced by two contradictory notions: On the one hand, users are conceptualized as “rational, individualized decision-makers” (2020, p. 9) while also having irrational fears of adopting AVs. Forms of public participation, like the test operation in Seestadt, are seen as the primary solution for reducing those concerns. Such notions also shaped the auto.Bus Seestadt project, as will be shown in the analysis. Regarding the governance discourse of acceptability, Stilgoe and Cohen (2021) pose a critical question: “Framing the public in terms of ‘acceptance’ prompts us to ask ‘acceptance of what?’” (2021, p. 4) Policymakers and private innovators present skeptical citizens as a barrier to the uptake of autonomous vehicles, but actually there is no tangible technological artifact that the public could accept or reject. Thus, the current discourse on automated driving remains highly unspecific and vague. Nevertheless, policy debates and forms of public participation tend to follow a deficit model in which the public needs to be educated so that it will support the implementation of the technology in the future. Rather than demanding unconditional trust, stakeholders should instead pose “the question of what place AVs could have in future mobility” (2021, p. 8). The auto.Bus Seestadt project was presented as being part of “confidence-building measures” (FFG Projektdatenbank, 2017) directed towards the public, which places it near the discourse of acceptability. According to this logic, passengers and road users had the opportunity to experience automated driving in real life, which potentially heightened their acceptance of the technology.

As the discussed studies show, safety concerns feature prominently in the acceptability discourse, albeit in a paradoxical way: AVs are being presented as offering significant safety improvements, but the technology is also recognized as a threat. The argument positioning self-driving cars as a profound contribution to road safety largely revolves around accident statistics and associated causes. A frequently referenced study in the US-American context attributes as much as 94% percent of all traffic accidents to human error

(Singh, 2015), and reports on the situation in Austria and worldwide present a similar picture (Bundesministerium für Inneres, 2021; WHO, 2021). Zipper (2021) argues that the fixation of policymakers, manufacturers, and autonomous vehicles stakeholders on the 94% mark is misguided. The blaming of individual drivers ignores systemic issues like poor road design and missing security features of cars, especially in the US. The widely held claim that AVs are more secure and will improve the situation currently lacks evidence. Quite the contrary: Stilgoe (2020) contextualizes the killing of Elaine Herzberg by an AV operated by Uber in 2018 as the consequence of deeming premature technology safe enough for the sake of rapid R&D. “This was artificial intelligence in the wild: not playing chess or translating text but steering two tonnes of metal” (2020, p. 2). The stakes are high, especially as the capabilities of humans are currently unmatched by any ADS. Instead of replacing drivers with software, most AVs today are accompanied by highly skilled professionals that act as “crutch” for the system to lean on during situations that it cannot handle safely (Tennant & Stilgoe, 2021). My fieldwork in Seestadt revealed the strong reliance of the buses on the human operator who monitored the vehicles at all times, as well as the infrastructural investments and adjustments that were necessary to guarantee the safe operation of the AVs.

As Herzberg’s death and several other severe accidents involving AVs have shown, there are pressing issues of accountability and ethics in relation to automated driving. Aside from the question whether automation software and manufacturers can be held responsible for technical failures (McCall et al., 2019), researchers have explored the ethical and moral implications of life-or-death situations in automated driving: “For example, the AV may avoid harming several pedestrians by swerving and sacrificing a passerby, or the AV may be faced with the choice of sacrificing its own passenger to save one or more pedestrians” (Jean-François, Azim, & Iyad, 2016, p. 1573). Nyholm and Smids (2016) point out that such considerations are based on the so-called trolley problem, a philosophical thought experiment they deem unfit for the evaluation of moral decisions made by automatic systems. JafariNaimi (2018) criticizes the underlying assumption that automation software should decide who lives or dies, as well as the utilitarian principle of “maximizing life” by killing or sparing people according to predefined variables. Situations concerning life and death should not be subjected to binary programming, as ethical questions are both highly situational and uncertain. Considering the state of the art of AVs, such thought experiments also lack any material basis, as the technology is nowhere near achieving the level of reflexivity and reactivity necessary to make such decisions.

2.2.3 Smart Cities and Infrastructures

Despite the preference of private companies like Google or Uber for "wicked dumb roads and wicked smart cars" (Albert, 2019, p. 246), many potential benefits of AVs depend on the cooperation between vehicles and smart infrastructures. Cooperative driving would be enabled by vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or even vehicle-to-everything (V2X) communication systems (Martínez-Díaz et al., 2019). These technologies follow the techno-utopian dream of perfect integration and can be related back to the early approaches to automated driving in the 20th century:

> The information provided by the infrastructure will be directly transferred to the vehicle controls using short-range wireless communication systems to automatically implement the optimal speeds, gaps etc. On their side, V2V communication allows interaction and collaboration among nearby vehicles without the intervention of a centralised entity. (Martínez-Díaz et al., 2019, p. 567)

While connected systems could mitigate some limitations of ego-only ADSs, there is no practical application yet (Yurtsever et al., 2020). For this approach to work, huge investments would have to be made: Besides the need for more advanced vehicle technology, most of the current transport infrastructure would have to be rebuilt or augmented. The necessary standards and networking technologies are currently being developed (Martínez-Díaz et al., 2019), but overall, the creation of such a massive digital infrastructure is still in its infancy.

The digitalization of infrastructures is not only pursued by stakeholders in automated transport but also by the smart city discourse. The auto.Bus Seestadt research project is especially interesting in this regard, as it explicitly linked the testing of AVs as a smart mobility technology to the Seestadt district as the proclaimed smart city development region of Vienna. In this case, notions of smartness seemed to reinforce and depend on one another. Kitchin (2014) summarizes how smart cities are being conceptualized. On a technological level, information and communication technologies (ICTs) automatically collect large amounts of data that is then used to surveil and analyze the city. The collection of big data on the urban sphere would allow for a real-time view of the city. The imaginaries of big data and fully autonomous cars are similar in this regard: both are presented as ultimate tools even though the reality of the technology is much more limited. On a political level, smart cities follow a neoliberal governance model focused on innovation, the knowledge economy, and the rationalization of city services and processes. Public relations material on Seestadt highlights this aspect by advertising a modern urban lifestyle, state of the art dwelling, and the presence of innovative businesses in the industry

4.0 sector (aspern. Die Seestadt Wiens, 2018). In the mobility sector, Intelligent transportation system (ITS) would allow, among other use cases, to track vehicles in real time. Such a system was in part realized for the test operation of the autonomous shuttles. The auto.Bus Seestadt research project also employed two additional sensory infrastructures during its runtime: The so-called Mobility Observation Box developed by researchers from the AIT automatically identifies different road users and their trajectories. This data can be used to analyze potential conflicts and evaluate the safety of the monitored road section (AIT, 2021a; AIT, 2021b). While this technology was only employed temporarily in the beginning of the implementation process, a camera system using Siemen's awareAI technology (Siemens, 2020; together.magazin, 2019) was installed at one intersection during the entire testing period. This I2V communication system monitored incoming road users, which in theory could have benefited the automated driving functions of the shuttles.

Smart city approaches are closely linked to business models of large IT companies like IBM, Cisco, or Siemens, who provide the necessary hardware and software as a product to city governments. Thus, the smart city discourse can be seen as a form of corporate storytelling (Söderström et al., 2014) that becomes performative by positioning corporations as obligatory passage points for urban development. IBM's smarter city campaign exemplifies two main rhetorical devices of this strategy: The city is framed as a system consisting of multiple subsystems that can be managed through technological means. Building on utopian themes, this technocratic management is presented as therapeutic treatment to urban communities otherwise deemed inefficient. As Söderström et al. make clear, the transformation of cities into smart systems creates a new ontology that puts companies and their products into power: "an engineering epistemology applied to humans and non-humans. Nature and culture reunited by the engineering mind" (2014, p. 314). The implementation of a smart electricity grid and the replacement of analog with digital electricity meters is a typical smart city application supposed to increase efficiency. In Seestadt, Siemens and other partners realized a similar project (UIV Urban Innovation Vienna GmbH, 2018). With reference to Kitchin (2014), Siemens makes use of system thinking typical to the smart city narrative: The city of the future would be based on four pillars – four technological systems – that could be seamlessly managed and automated (Siemens, 2019). Hughes' (1987) concept of Large Technological Systems (LTSs) offers a theoretical account of system thinking. His approach can be used to interpret cities as complex sociotechnical systems of systems. This conceptualization seems especially apt for understanding all kinds of urban infrastructures – like the test operation in Seestadt or the public transport network in general – that make up the urban whole. Hughes does not differentiate between technical and social elements of a system, because both are socially constructed by the central protagonist of his analysis – the system builder. Even though this conceptualization is asymmetrical by only attributing agency to human actors, it still provides insights into the challenge of establishing a new sociotechnical arrangement.

While the smart city narrative presents system thinking as a-political and neutral, it can have profound political implications. In her case study of Rajarhat New Town, India, Antenucchi (2021) studies the creation of segregated technological zones for the privileged through the implementation of smart city technologies. Sensors placed throughout the built environment make up digital sensing network that enforce the logic of border control across the urban sphere. With reference to Gabrys (2016), Antenucchi highlights the ontogenetic effects of sensing systems, which reconfigure the relationships between spaces, objects, and inhabitants: "The making of computing environments is, therefore, a relational process where computing becomes environmental, while at the same time, the environment becomes computational" (2021, pp. 91-92). As the case of New Town shows, smart cities enable environmental forms of governance with a strong discriminatory potential. Building on ANT notions, Graham (2002) studies the splintering of urban infrastructures into separated digital networks. Rather than conforming to the modern ideal of a uniform sociotechnical fabric covering all of urbanity, these infrastructure networks are limited to secluded, privileged zones both within a city or spread across the world. Graham approaches networked infrastructures as "sociotechnical hybrids that support the construction of multiple materialities and space–times" (2002, p. 185), thus deviating from conceptualizations of infrastructures as passive and fixed technological objects. Following this line of thinking, the smart city applications of Seestadt reconfigure the relations between inhabitants, the urban environment, and infrastructures in specific ways. In the analysis, I focus on how the test operation of the AVs affected the infrastructural networks of the district.

ANT approaches to urban studies (Farías & Bender, 2012) open new perspectives for conceptualizing these relationships by raising the ontological question of what the city is in the first place. It is not interpreted anymore as a singular entity, but as being assembled in multiple ways (Farías, 2012). The notion of urban assemblages highlights the procedural quality of urban realities: "It makes possible a double emphasis: on the material, actual and assembled, but also on the emergent, the processual and the multiple" (2012, p. 15). Building on the work of Deleuze and Guattari (1987), who popularized the concept, Müller

(2015) determines the most important characteristics of assemblages: They relate heterogenous entities to one another, thus producing a new whole. They constantly evolve through the processes of deterritorialization and reterritorialization, incorporating new elements and territories while rejecting others. And they are corporeal by reshaping and affecting bodies and perceptions. ANT and assemblage thinking share a lot of similarities, as both focus on sociomaterial processes, the heterogeneity of actors and associations, and their emergent quality. However, assemblage theory differs from ANT in one key aspect: It focuses on relations of exteriority, meaning "that the components parts of an assemblage can have intrinsic qualities outside associations that impact on and shape the assemblage" (Müller, 2015, p. 31). This notion is adopted for the study of urban assemblages by recognizing that different enactments of the city do not necessarily alter the identity of its elements (Farías, 2012).

The Transmilenio bus system of Bogotá, Columbia, holds insights into how public transport systems and the city coproduce each other. Pineda (2012) combines the ANT notion of scripts (Akrich, 1992) with LTSs (Hughes, 1987) and the concept of arenas of development (Jørgensen & Sørensen, 1999) to retrace the transformation of the former, so-called collective bus system into the Transmilenio. Taken together, these interrelated approaches allow me to conceptualize the material impact of the test operation on the district: This mobility infrastructure reassembled the district by enrolling both human and non-human actors, and by embedding new mobility devices, sensory networks, and ICTs in the urban fabric. The result was a specialized grid for experimentation that was in part exclusive to this application. Star and Ruhleder (Star, 1999; 1996) point out that studying infrastructures is difficult, as these are commonly seen as substrates and background for the actual task at hand. Furthermore, infrastructures are relational and become meaningful in practice, so that they have different meanings depending on the use case. The authors propose several guidelines for making the infrastructural characteristics of information systems visible in ethnographic work. These guidelines were also useful for conceptualizing the infrastructural dependencies of the test operation during fieldwork in Seestadt.

2.2.4 Governance and Implementation

The governance of automated driving technologies plays a key role in bridging the research and development of AVs and their implementation into society for different use cases. The technology requires new legislative frameworks, regulations, and infrastructures to function safely and reliably. As with many emergent technologies, policymaking is presented as lagging behind research and development. Stilgoe (2020) criticizes the dominance of software companies like Google, Facebook, and Uber over technologies deemed innovative, like AI and autonomous vehicles. Large enterprises would employ powerful stories of technological determinism for gaining political control while evading public oversight: It would be “easier for those in power to imagine the end of the world than the governance of innovation” (2020, p. 44).

Pfotenhauer et al. (2019) diagnose an innovation imperative in public policy, which presents innovation as the prime solution to all kinds of social issues. Based on the deficit model of the public understanding of science, the authors develop the deficit model of innovation. According to this model, a lack of innovation in a specific context can be remedied by concrete policy actions. The resulting initiatives are usually directed towards fostering entrepreneurship and investments into promising technoscientific fields. The result is a technocratic form of governance that profits from the “dual legitimacy of problem solving and economic prosperity” (2019, p. 898) commonly associated with innovation. Joly (2019) criticizes current innovation policies based on five myths of innovation. The most powerful myth is that of creative destruction, meaning that new technologies would inevitably eliminate existing ones. The disruption caused by innovative technologies is presented as beneficial to society, even though it might have severe sociopolitical implications. Another important point of reflection is the reduction of innovation to the emergence of new technologies, ignoring forms of social, bottom-up innovation. In the European Union, this imbalance is increasingly being challenged on the policy level.

In the case of autonomous vehicles, the technology’s attachments are largely obscured through an ideology Tennant and Stilgoe (2021) call autonomism. Policymakers are expected to facilitate innovation while innovators try “to escape from the societal discussion of either the means – how attachments might help the technology to work – or ends of AV technology” (2021, p. 18) This results in stakeholders trying to make automation work for the sake of it. As an alternative to this form of technological determinism, Stilgoe (2020) proposes the vision of the collaborative state: It would employ pro-active, experimental policies and forms of public participation in order to steer innovation according to the public’s interest.

In Europe, the CityMobil project (European Commission, 2013) funded by the sixth Framework Programme for Research and Technological Development (FP6) and the CityMobil2 project (European Commission, 2017) funded by the FP7 facilitated the research, development, and testing of automated road transport systems in urban contexts. Alessandrini et al. (2015) discuss the potential benefits and drawbacks of implementing AVs into urban transport infrastructures for four different use cases. Individual transport and private car ownership are expected to be gradually replaced by car-sharing services and collectively used autonomous vehicles. Urban freight transport is presented as another promising use case for AVs. The European Road Transport Research Advisory Council (ERTRAC) (2019) outlines three development paths for connected automated driving that are actively being pursued through a variety of projects. The mobility concept of the test operation in Seestadt fits in between the categories of urban shuttles and buses in the urban mobility development path, but the ERTRAC supposes the availability of level four automation technology for this decade, which remains a highly optimistic scenario. While the European policy discourse largely follows the innovation imperative and adopts the framing of ever-higher automation levels rather uncritically, there is a systemic discussion of the conditions and use cases of automated transport.

In Austria, the automation of driving as future vision for mobility is actively pursued by policymakers. The country was among the first to allow for the public testing of vehicles equipped with a level three automation system, albeit a security driver has to be present at all times (McCall et al., 2019). The legal basis for the testing of AVs was introduced in 2016 (Legal Information System of the Republic of Austria, 2016), with autonomous minibuses like the ones used in Seestadt being one of the proposed use cases. In the same year, the innovation program Action Plan Automated Driving (Federal Ministry of Transport, Innovation and Technology, 2016) laid out the national strategy for fostering automated transport. The auto.Bus Seestadt project originated from this call and explicitly references the CityMobil2 project on the European level (FFG Projektdatenbank, 2017). In 2018, the Action Plan was succeeded by the Action Programme on Automated Mobility (Ministry for Transport, Innovation and Technology, 2018).

The main aspirations linked to automation in these documents are road safety, sustainability, and innovation. The policies aim to realize these potentials by increasing testing activities, clarifying legal issues, enabling international cooperation, and by strengthening the position of the public sector and the national economy. Also, the importance of cooperative intelligent transport systems (C-ITS) is being highlighted. There is the conviction that strong regulations are needed to combat the potential adverse side effects of automated driving. In its Smart City Wien Framework Strategy (2019), the City of Vienna voices similar goals for the adoption of AVs as the Ministry of Transport. Electric AVs are imagined becoming part of the public transport infrastructure and ride-hailing services.

Towards the end of the state of the art, I want to elaborate on automated shuttle buses as a relatively popular use case. As previously argued, fleets of AVs deployed in a strongly delimited ODD are currently among the more feasible applications. The companies NAVYA, EasyMile, Baidu, and Local Motors have produced working autonomous minibuses with very similar feature sets. These systems are already being used for public transport services across the globe (Iclodean, Cordos, & Varga, 2020). The research project Shared Automated Mobility (2017) offers a slightly outdated list of tests, research projects, and key actors in the field on its homepage. Most of the listed projects only operate very small fleets of one to four vehicles. In Austria, the Digibus project (Salzburg Research, 2021) first tested a bus by NAVYA in 2017 in Koppl, Salzburg, and later switched to a vehicle produced by EasyMile. In Pörtschach, Carinthia, the SURAAA project (pdcp GmbH, 2021) operates a shuttle by NAVYA.

In the future, AVs could bridge gaps in the public transport network. Millonig and Fröhlich (2018) study whether autonomous minibuses could indeed satisfy passenger needs according to the four categories of availability, affordability, accessibility, and acceptability. Such shuttles would not replace high-capacity forms of public transport, like metros or conventional buses, but bridge the first and last mile of transit. However, AVs like the ones used in Seestadt will be seriously compromised, even if a fully functional system would be available in the future. While potentially providing better availability in rural areas and during times of low demand, conventional means of public transport perform better and are more cost-efficient. Research projects like the auto.Bus Seestadt project are presented as a way of optimizing the future design and operation of AVs according to user needs. Especially the communication with passengers without the presence of a human driver appears challenging. Rehrl and Zankl (2018) summarize the findings of the Digibus project, which presents an interesting baseline for comparison with the operation in Seestadt. Albeit both projects use very similar vehicles by NAVYA for a first/last mile scenario, they also differ in key aspects: Koppl is a rural area, and the road and traffic conditions are more challenging for the ADS than the relatively simple road network of the suburban Seestadt quarter. The implementation process was similar, especially regarding the mapping of the route and the infrastructure required for the precise localization of the vehicles.

Following the governance framework of acceptance (Stilgoe & Cohen, 2021), a shared interest among research projects on automated shuttles (Mouratidis & Serrano, 2021; Rehrl & Zankl, 2018; Salonen & Haavisto, 2019) are the sentiments of users and participants towards the technology. These projects put both the technology and the citizens to test, with the underlying assumption that both aspects need to be optimized for the future of automated transport. But as Mouratidis and Serrano (2021) recognize, these findings are limited to the conditions of the experiment and cannot be easily translated to future implementations. Nevertheless, it was interesting to investigate how the partners of the auto.Bus Seestadt project evaluate the performance of the shuttles and the acceptance of the technology by tourists and inhabitants. The Ministry for Transport, Innovation and Technology published the reports of all projects that tested AVs in Austria to date (Bundesministerium für Verkehr, Innovation und Technologie, 2020), including the auto.Bus project. This study adds to the official report by exploring its material impact on the quarter and the operational routine in greater detail.

3 Research Questions

After having discussed the existing research on automated driving and its relevance to this study, I now want to state my approach and research interests. When thinking about the elements which make up the test operation, the semi-autonomous buses might appear as the central piece of the puzzle. Most public discourses on automated driving focus on technological artifacts and their functions. The Autonom Shuttle by NAVYA (2020) definitely is a fascinating piece of technology with its cute looks and elaborate fusion of different sensors. So is the software enabling the automation of driving. But the automation technology only becomes meaningful through its social connections and infrastructural embedding. The novelty of the auto.Bus Seestadt project not only stemmed from the vehicles themselves – they presented an already finished product accompanied by extensive support from the manufacturer – but also from the way these AVs were embedded in the urban environment of Seestadt. Therefore, the process of implementation is highly relevant to this case. I conceptualize this process as the re-assembly of mobility, taking a holistic approach interested in all the human actors, technologies, and infrastructures that were assembled into the network of the test operation. To study the re-assembly of mobility, I pose the following main research question:

> (MQ) How did the project partners adapt the automation technology and the Seestadt quarter for the re-assembly of mobility?

Automation is not a minor new feature of automobiles used for public transport. It requires the complete reconceptualization of basically all aspects that shape a mobility service: the vehicles' functions, the operational procedures and conditions, safety and liability, the role of personnel supervising the operation, maintenance, the cooperation between service providers and manufacturers, the usage patterns of passengers, as well as the urban infrastructures and datasets needed to enable the automation. The aim of the project partners was to research these issues by deploying two AVs under real-world conditions. As full automation is out of reach, every implementation of automated driving remains partial and involves compromises regarding the degree of automation and the autonomy of the vehicles. The main research question explores the concrete materialization of the technology. It focuses on the adaptations of the automated driving system, the built environment, and the local infrastructures that were necessary for making the operation feasible. I further specify my interest in the implementation of the AVs by posing three additional subquestions:

> (SQ1) How did the project partners reassemble Seestadt and its infrastructures for the test operation?

The project partners did not encounter tabula rasa in Seestadt. Instead, they adapted the operation of the AVs to the existing built environment, infrastructures, and ways of life. At the same time, the test operation also transformed the urban fabric of Seestadt. The first subquestion investigates how new and existing infrastructures were reassembled for the automation of driving. Seestadt's status as a smart city development area presented a fecund ground for the project. The district only recently made the jump from the drawing board into reality, so its social and infrastructural relations are still in flux. As the AVs did not replace existing mobility services, like metro or bus lines, the project partner had the opportunity to test the technology without causing major disruption. The experimental character of the project and its interrelations with the local smart city infrastructure were important leads for tracing how the actor-network of the test operation got formed.

The recombination of infrastructures for the test operation related to the limitations and interdependences of the automated driving system and the design of the test operation. The second subquestion explores these aspects in detail:

> (SQ2) How and under which conditions is the automation of driving accomplished by the actors of the network?

Despite NAVYA's marketing of the shuttles as "fully autonomous, driverless, and electric" (2020, p. 4), the state of the art of automated driving shows that current technologies are severely limited and not autonomous by any means. In the case of the test operation, human operators supervised the performance of the vehicle at all times, made decisions that the ADS could not handle, and took over control at certain sections of the route. In addition, the automated driving functions of the buses depended on a large variety of supportive technologies: sensors integrated into the vehicle and the environment, digital networks like GPS and cellular data, the programming of the vehicles, and detailed maps of the environment. Accomplishing the partial automation of driving was an effort that required the close cooperation between all actors of the actor-network. The second subquestion aims at getting an overview of the involved actors, describing their roles in the operation, and conceptualizing the limitations of the operation.

Key to understanding the re-assembly of mobility and the actor-network of the test operation is the coalition of the project partners and their efforts in building this network over the duration of the auto.Bus Seestadt research project. The third subquestion investigates the roles of the project partners in the experiment:

> (SQ 3) What did the different project partners contribute to the test operation and what was their interest in the research project?

The six project partners of the auto.Bus Seestadt project (Wiener Linien, AIT, KFV, TÜV, Siemens, and NAVYA) positioned themselves as spokespersons of the AVs – they claimed responsibility for their successful deployment and operation. The project consortium was not a homogenous group, but an interdisciplinary team. The various institutions, organizations, and companies are experts in their respective field and mobilized different networks for a shared goal: the testing of the AVs through the means of the operation in Seestadt. They also got external supporters, among them the aspern.mobil LAB, the district, local politicians, the ministry, and the consultative agency AustriaTech, as an important contact for organizations wanting to test AVs in Austria.

I interpret the project partners as central actors and builders of the network of the test operation. Conceptualizing their roles and interests in the research project yielded important insights regarding the goals of the operation. By closely listening to the stories told by my interview partners, I traced the various steps of the re-assembly of Seestadt, the construction of the test operation, and the evolution of the research project.

4 Sensitizing Concepts

My research objective is to understand how the project partners implemented the test operation into Seestadt and how this experimental mobility infrastructure impacted the urban environment. To answer the posed research questions, I require fitting sensitizing concepts for analyzing the different steps of the implementation process, the role of involved parties, and the interrelations between the test operation and the quarter. The first step of developing the chosen theoretical approach was to reflect on who and what took part in the test of the AVs: On the one hand, the project involved a large variety of objects, infrastructures, and technologies, among them: the buses, various sensors, software, algorithms, datasets, GPS, stops, and roads. On the other hand, a lot of human actors were necessary, among them: engineers, scientists, company representatives, technicians, operators, citizens, and passengers. For the experiment of the test operation to work, ties between human subjects, technologies, infrastructures, and the built environment had to be built and consolidated. The general idea of autonomous vehicles is based on the conviction that machines possess a certain degree of agency. But as the state of the art showed, the agency of AVs in return depends on the relationships between many technical components, as well as on the cooperation of humans.

These rather intuitive observations lead to my argument that actor-network-theory provides me with fitting concepts and analytical approaches to answer the posed research questions. In this chapter, I elaborate on works already mentioned in the state of the art and adapt their theoretical contributions for this study. The discussed sources predominantly belong to what Michael (2017) calls the classical phase of ANT, which in the 1980s and 1990s laid the grounds for future studies and Post-ANT approaches. I start by outlining the central premises of ANT and the various steps in building a network. Then I describe the processes of simplification and black-boxing as means to stabilize a network. I continue with an examination of the role of non-humans in society and technological processes. Last, I expand the theoretical framework with ANT approaches to urban studies and the concept of networked infrastructures.

4.1 The Social as Relational

What does it mean to understand the test operation and the auto.Bus Seestadt research project as an actor-network rather than through other theoretical lenses? Michael (2017) summarizes the key principles of ANT. The most important presumption is that “the social is ‘flat’” (2017, p. 4), meaning that social relations are organized on a horizontal plane instead of a vertical hierarchy. Through this change in perspective, dominant social science categories like sex, class or gender are not readily applicable anymore, as the conceptualization of agency and power by ANT is radically different: “One therefore does not study ‘power’ but ‘relations of power’” (2017, p. 22). The change in perspective from vertical hierarchies to horizontal relations also dissolves the distinction between the macro and micro level of analysis. Accordingly, ANT does not differentiate between small micro-and large macro-actors. Instead, they are considered as being isomorphic, which “does not mean that all actors have the same size but that a priori there is no way to decide the size since it is the consequence of a long struggle” (Callon & Latour, 1981, p. 280). This conceptualization relates to another key difference of ANT compared to other social science theories: “Instead of dividing the subject with the social/technical, or with the human/animal, or with the micro/macro dichotomies” (1981, p. 284), it attributes agency to all human and non-human actors alike. Therefore, the social is not limited to human subjects anymore, but emerges out of the associations between heterogeneous actors. Taken together, these basic principles already hint at how an actor-network comes into being: It is the outcome of struggles between actors to incorporate others, grow in size, and become powerful.

Through the reconceptualization of the social by ANT, the auto.Bus Seestadt project appears in a new light: The project partners still play an important role, but their relationship to the other involved human and non-human actors becomes an open question. If things and technologies like the buses, GPS, or LiDAR sensors possess agency and interact on the same level as humans and their organizations, then the participation of non-human actors in the actor-network is not a given, but the outcome of negotiations. Therefore, the auto.Bus Seestadt project not only tested the shuttle buses but also all the other actors and their associations to the network. I interpret the implementation of the AVs into Seestadt as the process of building and stabilizing an actor-network. How can I study its formation?

Michael explains that a common approach for conducting an ANT study is to follow the actors one encounters in a situation while “avoiding presuppositions over the ‘what’, ‘who’ and ‘how’ of network-building” (2017, p. 26). Instead of presupposing the answers to these questions, researchers should learn about the actors through open-ended empirical engagement. Callon (1986a) conceptualized these considerations through three methodological principles: The first principle is generalized agnosticism, which “refrains from judging the way in which the actors analyze the society which surrounds them” (1986a, p. 200). The identity of actors should not be forced upon them, but observed as it comes into being. The second principle is generalized symmetry, according to which both technical and social, as well as human and non-human forces should be studied symmetrically using “a single repertoire” (1986a, p. 200). To this end, ANT employs a specialized vocabulary I will establish in the following subchapters. The third principle is free association, which strives to abandon “all a priori distinctions between natural and social events" (1986a, p. 200). When considering all three principles, the auto.Bus Seestadt project presented an assemblage of unidentified, isomorphic actors whose interests and associations were unknown to me before the start of empirical research. To learn about their identities and roles, I had to follow them around their habitat. I continue with discussing the central concepts and vocabulary used to analyze the formation of actor-networks.

4.2 Translation and Network Building

As described previously, an actor grows by associating more and more other actors to the network it is trying to build. But how does an actor bind another actor to the network? This is achieved through the means of translation. "To translate is to displace" (Callon, 1986a, p. 223), thus encompassing the transformation of the translated entity. In Callon's prominent case of the scallops and fishermen of St Brieuc Bay, a group of scientists tries to translate the interests of all other actors into a shared goal: the sustainable cultivation and preservation of scallops. The moment of successful translation would have been the constitutive moment of the actor-network, positioning the scientists as the spokespersons of the network. The disparate voices of all the involved actors would have been translated into the uniform voice of the scientists. Callon and Latour describe the manifold process of translation as follows: "By translation we understand all the negotiations, intrigues, calculations, acts of persuasion and violence, thanks to which an actor or force takes, or causes to be conferred on itself, authority to speak or act on behalf of another actor or force" (1981, p. 279).

To translate, then, is to create partial order out of chaos. It is a creative and constructive practice. Following Callon's (1986a) three principles, we should not presuppose the character of an actor. Instead, the identity of an actor can only get known by studying its displacement and transformation throughout translation. Through translation, an actor brings another actor into being and materializes it in relation to the specific reality of the actor-network: "By stating what belongs to the past, and of what the future consists, by defining what comes before and what comes after, by building up balance sheets, by drawing up chronologies, it imposes its own space and time" (Callon & Latour, 1981, p. 286). From an ANT perspective, the implementation of the test operation into Seestadt involved the project partners displacing different actors from their point of origin and moving them to the space-time of the network. Through the means of translation, the identities of the actors were transformed to fit this new reality. So in order to understand how the network came into being, one needs to retrace the translation of actors. But how is translation achieved? To answer this question, a more profound understanding of how networks are built and how actors relate to one another is required.

Callon's study (1986b) on the attempts of the Electricité de France (EDF) to develop the véhicule électrique (VEL) during the 1970s is a case of network building similar to mine. The VEL should have revolutionized automobility by using an electric drive, just like the self-driving buses were supposed to pave the way for automated public transport. In order to realize the VEL, the EDF created a narrative of social as well as technological change and tried to mobilize a large variety of actors from different areas, like research, development, manufacturing, and policymaking. Non-human actors like fuels cells and accumulator also played a key role in the project's success. The actor-network is where all actors join forces. It "associates heterogeneous entities. It defines their identity, the roles they should play, the nature of the bonds that unite them, their respective sizes and the history in which they participate" (1986b, p. 24).

Callon identifies the EDF as powerful technoscientific actor trying to bend reality to its will. But the EDF and the vision of the VEL are only as powerful as the associations between the actors are durable, so that the EDF does not possess power by itself. When several actors refused their translation, the entire network, and with it the VEL, broke down. I approached the test operation in Seestadt as a similarly fragile reality: The automation of driving depended on the successful translation of the involved actors. The process of translation can be separated into four steps serving different purposes, which I discuss next.

In both the cases of the VEL and the scallops, the respective technoscientists first posed a problematization that defined the basic structure and goals of the network: Through problematization, the actors building the network rendered themselves indispensable by presenting the network as the solution to the challenges that the actors faced. The argument can be summarized as follows: To revolutionize mobility and preserve the scallops, the actors had to support the construction of the VEL and the experiments of the scientists to anchor the larvae of the clams. Problematization works through the creation of obligatory passage points (OPPs), defined as a "passageway through which all the other entities that make up its world must pass. To translate, then, is to oblige an entity to consent to detour" (Callon, 1986b, p. 26). A first instance of displacement and transformation takes place. Problematization is followed by the stages of interessement, enrolment, and mobilization. During the first two steps, fitting identities and roles are imposed on the actors. The challenge is to create equivalences between the interests of the addressed parties and the objective of the network through negotiation and force: If the scallops wanted to reproduce, they had to follow the scientists' instructions. If Renault wanted to stay a relevant manufacturer, they had to produce the VEL instead of another car powered by a combustion engine.

When translating these concepts to the auto.Bus Seestadt project, it was already clear from the project's description that the consortium positioned the test operation as the solution to certain problems connected to the larger issue of automated driving. To realize their vision, the project partners had to define the identities and roles of the actors that took part in the experiment. For example, the Autonom Shuttle by NAVYA could be used for a large variety of applications, but for the test operation in Seestadt, the vehicles as non-human actors had to be convinced of fulfilling a very specific purpose. The shuttles deployed in Seestadt differed from the archetype. As I will show in the analysis, it would have been impossible to just cart a minibus from the assembly line in France to Vienna and start the operation. The AVs had to be adapted to function under the particular circumstances, which was a challenging and lengthy process. From an ANT perspective, the same goes for all the other human- and non-human actors, whether or not they were already located in Seestadt. Becoming part of a network always encompasses displacement and transformation, which some actors might resist strongly.

The last step in the process of translation is the mobilization of enrolled actors. Up to this point, it remains unclear whether they will actually join forces in the network. Mobilization is complicated by the heterogeneity of both the actors and their relationships: "Each actor of a network enrols a mass of silent others from which it draws its strength and credibility" (Callon, 1986b, pp. 31-32). Accordingly, every point of a network forms a network in itself. Translation simplifies this heterogeneity by addressing only selected individuals of a collective, for example, a group of scientists as representatives of the scientific community, or a working battery as the representative of all its technical and chemical components. This movement of zooming in and out on certain actors and networks is especially relevant to my case study: Actors like the autonomous shuttles comprise a complex software and hardware architecture that combines multiple networks into a seemingly self-contained product. The same principle is applicable to the sensory infrastructure of the test operation. After enrolling individual spokespersons for the actor-network, it remains to be seen whether these manage to mobilize their communities. "Will the masses follow their representatives?" (Callon, 1986a, p. 214) If they do so, then the translation of actors is successful, and the collective of actors gets displaced into the network's reality. Following the conceptualization of the test ride as re-assembly of mobility, I focused on how existing actors and networks got displaced and reassembled with new actors to form the infrastructure of the test operation. Did the formation of this actor-network go as expected? Did the project partners and their allies translate all the necessary actors? These questions will be answered in the analysis.

Even if all collectives can be mobilized, translation remains a delicate state. In both of Callon's cases, this process eventually failed: "Translation becomes treason, *tradutore-traditore*, once an enrolled entity refuses to enter the actor-world in order to expand into others" (Callon, 1986b, p. 26). As a network is only as powerful as its associations, every disassociation endangers the entire structure. Translation is neither guaranteed nor final but requires ongoing negotiations through which the network builders try to overcome the "resistivity" (Callon & Latour, 1981, p. 284) of actors against their displacement. There are several tools for easing translation and making the resulting associations more durable. In the next subchapter, I discuss the means of simplification, juxtaposition, and the creation of black boxes. In addition, I elaborate on the delegation of tasks from humans to non-humans, which is highly relevant for automation technologies like AVs.

4.3 Simplifications and Black Boxes

Actor-networks are defined by heterogeneity, which relates to both the actors and their associations. To integrate actors into the network and create a stable structure, this complexity has to be reduced. Network builders like the EDF or the partners of the auto.Bus Seestadt project tie "together all these scattered elements into a chain in which they are all indissociably linked" (Callon & Latour, 1981, p. 289). The creation of such a chain of associations is facilitated by simplification and juxtaposition.

Simplification can be defined as "the reduction of an infinitely complex world by means of translation" (Callon, 1986b, p. 29). It is tied to the processes of interessement and enrolment, as the heterogeneity of an actor is reduced to a specific identity and corresponding role. The simplified actor then gets juxtaposed into the network: "Through the designation of the successive spokesmen and the settlement of a series of equivalencies, all these actors are first displaced and then reassembled at a certain place at a particular time" (Callon, 1986a, p. 217). The ADS of the autonomous minibuses exemplifies the need for simplification quite well: Its architecture consists of many software and hardware components which have to seamlessly interlock to enable the automation.

Therefore, the complexity of components, like the array of different sensors, has to be reduced so that it can be juxtaposed into the large whole of the automated driving system. As actor-networks are not limited to their technical dimension (Latour, 1996), the same applies to other sets of relations: The interaction between the operators, passengers, and AVs opens unlimited possibilities, but the test operation depended on a simplified routine limiting the range of actions. If the relations between the actors of the network would have been questioned all the time, then the buses would not have moved at all. For the operation to work, the actors had to be simplified and juxtaposed: "The simplifications are only possible if elements are juxtaposed in a network of relations; but the juxtaposition of elements conversely requires that they be simplified" (Callon, 1986b, p. 30). Whether and how this was achieved will be derived from my empirical observations.

Like the process of translation, simplification is neither given nor guaranteed, but results from ongoing negotiations. It might be uncovered as "impoverished betrayal" (Callon, 1986b, p. 29) once an issue or actor points out the actual complexity of the situation. For example, the sensors of automated driving systems get confused by certain weather conditions. When this subsystem behaves suboptimal, the simplified differentiation of driving tasks into subtasks is being questioned and the automation fails. A powerful way of preventing the collapse of simplifications is the creation of black boxes: Such a box "contains that which no longer needs to be reconsidered, those things whose contents have become a matter of indifference" (Callon & Latour, 1981, p. 285). The geometric shape and opaqueness of a cuboid already conveys a strong sense of durability and persistence. Opening such a Pandora's box and examining its contents seems unadvisable. Therefore, "an actor grows with the number of relations he or she can put … in black boxes" (1981, pp. 284-285).

As will be shown in the analysis, the process of black-boxing was one of the most pressing challenges of the test operation. Even though the automation of public transport was far from being black-boxed, the auto.Bus Seestadt project was a step in this direction. The project partners also relied on innumerable existing black boxes and infrastructures, like electricity, roads, GPS, cameras, lasers, the operational procedure of a bus line, or the relationship between passengers and bus drivers/operators. However, a black box might be opened at any time, jeopardizing the entire network. Applying ANT involves exactly that: One has to zoom into the black boxes to get a good look at the hidden networks and associations supporting the actor-network. In the analysis, I open the most important boxes of the test operation, among them the chain of automation powering the shuttles and the infrastructural actors they depended on.

The process of building the network of the test operation now appears as a daunting task. The project partners had to translate numerous human and non-human actors into the network while simplifying their associations despite their heterogeneity. Before discussing ANT approaches to studying urban spaces and infrastructures, I want to reflect on the role of non-humans in technological practices like automation. After all, the dream of autonomous vehicles rests on the idea that a combination of hardware and software can replace drivers. Thus, non-human actors are entrusted with responsibilities previously held by humans, leading to the reconfiguration of relations between humans and machines.

4.4 Non-Humans and Delegations

Latour (Johnson, 1988; 1992) reflects on the delegation of tasks to technology using the example of the automatic door closer. This technology presumes the existence of doors and door hinges, which Latour recognizes as groundbreaking inventions: They enable us to open and close a hole in the wall without the need to constantly rebuild the structure. Instead, this task is delegated to a non-human – the hinge – which performs the task with minimal effort: "I will define this transformation of a major effort into a minor one by the word translation or delegation; I will say that we have delegated (or translated or displaced or shifted out) to the hinge the work of reversibly solving the hole-wall dilemma" (Latour, 1992, p. 229). The hinge reverses the force and time humans would need to open and close the hole in the wall. In a similar vein, the car reverses the efforts that would be necessary to travel a long distance by foot. Latour conceptualizes the established relationships between humans and non-humans through Akrich's concept of the script: "Like a film script, technical objects define a framework of action together with the actors and the space in which they are supposed to act" (1992, p. 208). Passersby are supposed to open the door with the help of the hinge and close it afterwards.

In reality, this interaction is prone to failure: People constantly go off script and leave the door open. This dilemma could be resolved by adding another human to the situation: a porter operating the hinge. But employing a potentially unreliable employee contradicts the reversal of forces achieved through the non-human hinge: "A simple task, forcing people to close the door, is now performed at an incredible cost; the minimum effect is obtained with maximum spending and spanking" (Latour, 1992, p. 300). The technology of the door closer reverses forces and times yet again, as it always performs the delegated task once installed: "A nonhuman (hinges) plus another nonhuman (groom) have solved the hole-wall dilemma" (1992, p. 301) Translating this idea to the case of autonomous vehicles, automated driving systems are presented as a way of finally freeing individual transport from unreliable drivers. According to this imaginary, their training and discipling, as well as the actual operation of the vehicle present a great waste of efforts, especially as drivers constantly enact their own de-scriptions, deviating from the pre-scriptions enforced by non-human actors like speed traps, road signs, and traffic regulations (Akrich, 1992).

Such discourse follows a reductionist and instrumental understanding of technology, as it does not consider a key requirement of translation: "When humans are displaced and deskilled, nonhumans have to be upgraded and reskilled" (Johnson, 1988, p. 301). This statement is connected to the central premise of ANT and technological politics (Winner, 1986): Non-human actors have agency. They enact certain morals, expectations, and even discriminations. The notion of the script also highlights that every technological process involves pre-scriptions defining how human actors are expected to behave. Returning to the example of the door closer, its spring might be so strong that certain people are unable to open the door, or that the next person might be hit by the rebounding door. Either the humans have to adjust, or the non-humans have to be augmented, e.g. by adding a hydraulic system that retains some of the applied force. Technology might also refuse to work as expected by going on strike or breaking down. For the case of AVs and the auto.Bus Seestadt research project in particular, this perspective helps to understand the complex interaction between humans and machine in automated driving. As the task of driving is split into minute subtasks delegated to the non-human subsystems of the ADS, an ever-increasing series of interlocking scripts is produced. Currently, these inscriptions fail at fully realizing the reversal of force and time offered by translation: Human operators always oversaw the automatic driving of the shuttles in Seestadt, presenting a great investment of resources.

Of course, experimenting with automated driving on public roads is much more complex than closing a door, and the stakes are much higher. Chapter six explores the relationship between the non-human actors of the automation system, the human operators, and the infrastructures of Seestadt in greater detail. The goal is to understand how the project partners translated the involved actors into a chain capable of partially automating the operation of public transport. This endeavor involved a series of scripts delegating tasks to the human and non-human elements of the actor-network while taking care of potential disruptions and misunderstandings. To properly account for all aspects of the test operation, I also need to consider the environment of Seestadt as the locus of action. The recent uptake of ANT approaches by urban studies provides me with concepts for conceptualizing the relations between the auto.Bus Seestadt project, the district, and its infrastructures, as well as Seestadt's status as a smart city.

4.5 Urban Assemblages

A network does not exist in vacuum but is part of a specific spatiotemporal context. Seestadt as a promising smart city development region is of special importance to the test operation, as it was embedded in this urban environment, leading to reciprocal adaptations. Understanding a city or a city district is an epistemological and ontological challenge in itself. Accordingly, urban studies struggles to define its very object of study: What is a city? What does it encompass? Where does it begin and where does it end? Recapitulating the prominent discourses in the field, Farías (2012) recognizes two theoretical extremes: Either the urban is interpreted as a totality, or it is deconstructed into non-existence. The Seestadt quarter poses a similar challenge to this study: There seemed to be a strong connection between the design of the test operation and the local conditions. This interdependence both comprised and exceeded the sum of geographical coordinates, topographical features, roads, buildings, public infrastructures, demographics, communities, and places of consumption and work. The test operation had a material impact on the district, but these changes did not lead to a radically different city. Seestadt was still Seestadt. How can I conceptualize the transformations enacted by the auto.Bus Seestadt project?

Recent advances in adopting ANT approaches for urban studies present the opportunity to resolve this conundrum. From this perspective, the city is conceived as an assemblage, "as a multiplicity of processes of becoming, affixing sociotechnical networks, hybrid collectives and alternative topologies" (Farías, 2012, p. 2) To study the city means to study "heterogeneous connections … that 'assemble' the city in multiple ways" (2012, p. 14). I employ this approach for my study, so that the implementation of the test operation appears as the process of assembling Seestadt in a specific way: The project partners not only moved the buses and the operators to Seestadt, but they also placed stops in the environment, defined a route through the local road network, created a detailed map of the surroundings, weaved additional sensors into the urban environment, and offered a new mode of transport to local citizens and tourists. Thus, the test operation reassembled the district according to the needs of the research project.

Latour underlines the potential of actor-networks in restructuring space beyond the constraints of Euclidean space:

> The first advantage of thinking in terms of networks is that we get rid of "the tyranny of distance" or proximity; elements which are close when disconnected may be infinitely remote if their connections are analyzed; conversely, elements which would appear as infinitely distant may be close when their connections are brought back into the picture. (1996, p. 371)

For ANT, space is not universal. Networks connect disparate locations and the gaps between these places do not have to be filled in like on a conventional map: "There is no aether in which the networks should be immersed" (Latour, 1996, p. 371). Relating these insights to the concept of urban assemblages, I focused on how the actor-network of the test operation reassembled parts of urbanity for the automation of public transport while leaving others untouched. From this theoretical perspective, there are innumerable assemblages of Seestadt, and neither of them is all-encompassing nor exclusive, as assemblage thinking recognizes that entities have certain qualities regardless of how they are assembled (Müller, 2015).

When reflecting on the interdependence between the autonomous shuttle buses and the urban environment, there is also the issue of infrastructures. On the one hand, the test operation presented an infrastructure for the automation of driving. On the other hand, the test operation reassembled new and existing infrastructures for this experiment, among them the road and public transport network, digital networks like cellular data and GPS, as well as sensors like cameras placed in the environment. Commonly, infrastructures are conceived as the precondition for the actual task, thus framing them as invisible and passive (Star, 1999). Considering the strong reliance of automated driving systems on infrastructures and the attribution of agency to non-human actors by ANT, I approach the infrastructural components of the test operation as essential parts of the network. Graham's (2002) concept of networked infrastructures provided me with fitting theoretical tools to study these relations. Building on ANT, he interprets the construction infrastructures as "the linkage of massive, heterogeneous arrays of technological elements and actors" (2002, p. 185). Thus, infrastructures are a kind of actor-network. They are not fixed but the outcome of negotiations, not solely technological but sociotechnical. Rather than forming the passive background of urban life, Graham positions infrastructures as agents of change that "support the construction of multiple materialities and space–times" (2002, p. 185).

Combining all the outlined sensitizing concepts, the construction of the networked infrastructure of the test operation appears as the means through which the project partners of the auto.Bus Seestadt reassembled the district for automated public transport. The resulting actor-network involved both human and non-human actors. It was embedded in the urban fabric of the district and provided a complex array of scripts that enabled the distribution of tasks between the operators, the automation system, and the infrastructural components of the network. How this actor-network came to be and what actors and associations it encompassed are questions that can only be answered by studying its material conditions. In the next chapter, I describe the methodological approach for doing so.

5 Building a Case Study

This chapter reflects on how the empirical research was conducted. Based on the posed research questions and the chosen sensitizing concepts, the first challenge was to find a suitable approach to getting to know the actors involved in test operation and understanding the role of the project partners. ANT already provides a loose methodological framework through the principle of following the actor:

> Instead of imposing a pre-established grid of analysis upon these, the observer follows the actors in order to identify the manner in which these define and associate the different elements by which they build and explain their world, whether it be social or natural. (Callon, 1986a, p. 201)

As Michael stresses, the focus on the empirical situation and the use of specialized vocabulary helps “avoiding presuppositions over the ‘what’, ‘who’ and ‘how’ of network-building” (2017, p. 26). So in order to analyze the actor-network of the auto.Bus Seestadt research project and the test operation, I tried to get as close as possible to the humans and non-humans who were part of this re-assembly. While social science research employs both quantitative and qualitative methods depending on the specific context and aim of the study (Jensen & Laurie, 2016; Silverman, 2000), I concluded that qualitative methods fit the research interests the most. The use of ANT combined with the narrow focus on the associations between the actors of the test operation contradicts the use of quantitative approaches. I aimed at inductively learning about the quality of social relations rather than their quantification according to predetermined metrics. In the very beginning, I considered studying the users of the shuttle buses based on the discourse of acceptance (Graf & Sonnberger, 2020; PAVE, 2020; Stilgoe & Cohen, 2021). For example, I could have conducted a representative survey of the passengers’ experiences and sentiments. But as my research interest shifted towards the implementation process and as I learned that the project consortium already studied the users on multiple occasions, I decided against this option. In the next subchapter, I explain my general considerations for studying the actor-network of the test operation.

5.1 Approaching the Test Operation

From the start, grounded theory (Charmaz, 2006; Glaser & Strauss, 1967) provided me with useful guidelines for creating a qualitative research design that synergized with ANT's principle of following the actor. The basic premise of grounded theory is to base theoretical abstractions on the analysis of empirical observations, thus advocating an inductive approach to the production of scientific knowledge. In practice, this means that the researcher constantly moves between data collection and analysis in order to develop substantive theories that are mostly limited to the studied phenomenon. As a reaction to its remaining positivistic assumptions, Charmaz (2006) reorients grounded theory towards constructivist positions. Rather than disjoining the researcher from the data and the derived theories, she argues that "we construct our grounded theories through our past and present involvements and interactions with people, perspectives, and research practices" (2006, p. 10). Building on this critique, Clarke (2005) adapts grounded theory to the postmodern turn. Her methodology of situational analysis is based on several principles:

- Acknowledging that knowledge is always embodied, both on the side of the researcher and the researched.
- Grounding the researched phenomenon in its larger situation, thus recognizing that it comprises different perspectives that are related to one another.
- Focusing on heterogeneity and difference in a situation rather than on homogeneity: "The goal is to understand, make known, and represent heterogeneity of positions taken in the situation under study" (2005, p. 25).
- Developing sensitizing concepts and engaging in theorizing as a process rather than striving for a substantial or formalized theory.

I employed situational analysis for constructing an ANT analysis of the auto.Bus Seestadt research project. There are similarities and synergies between these approaches, as both focus on heterogeneity. ANT provides the necessary vocabulary and concepts for engaging with the test operation as situation and actor-network. Such an account is inevitably limited by the choice on which actors to focus on: "To the extent that the analytic narrative of ANT orients around a 'prime mover' this is a matter of convenience – a practical condition for rendering an account manageable" (Michael, 2017, p. 35). As knowledge is embodied, one needs to recognize that practical choices regarding the perspective of analysis determine whose account of a situation is privileged. For the operationalization of situational analysis, Clarke proposes different cartographic exercises. These are used to orient oneself in the collected data, analyze the situation, and create theory as an ongoing process. I will elaborate on the use of such maps throughout the research process in the following subchapters.

Reflecting on the available qualitative social science methods for data collection (Saldaña, 2011), I decided on two main approaches for accessing the actor-network: As the test operation was still ongoing at the moment of data collection, I conducted fieldwork in Seestadt and tried out the buses myself. The resulting autoethnography (Ellis, Adams, & Bochner, 2011; Ellis & Bochner, 2000; Marak, 2015) greatly contributed to my research interest. I was able to reflect on my own reactions and feelings towards this mobility innovation while studying the relations between the heterogenous actors, like the AVs, the operators, and urban infrastructures. However, the insights from fieldwork were limited because the network of the test operation already had been stabilized. It would have been difficult to trace the implementation process and the evolution of the research project solely based on this data. Therefore, I decided to conduct problem-centered interviews (PCIs) (Witzel & Reiter, 2012) with representatives of the project partners and the aspern.mobil LAB as a supportive third party. I depend on the stories told by my interview partners for reconstructing the creation of the actor-network. During analysis, I compared their accounts to one another and related the interviews to the ethnographic data in order to answer the posed research questions.

The following three subchapters detail the major phases of conducting the research on the auto.Bus Seestadt project. I started by creating various maps of the involved actors and then moved on to explorative ethnographic fieldwork in Seestadt. The preliminary insights from the first phase of research helped me to decide on potential interview partners and questions. Following grounded theory guidelines, I started analyzing each interview right away to allow for theoretical sampling. Finally, I performed multiple rounds of coding, prepared the results through memo writing, verified my findings with the help of the ethnographic data and the state of the art, and developed a concept for the presentation of results.

5.2 Studying the Network through Myself

As stated in the introductory vignette, I first learned about the test operation in the winter of 2019 while working on a student project. Ever since, I have been engaging with automated driving and the auto.Bus Seestadt research project in particular. Before actually starting the empirical research for this study, I first tried to explicate all relevant information and experiences I had accumulated over time: previous visits to Seestadt, prior conversations with one of the operators,[3] publicly available material on the research project, as well as existing research presented in the state of the art. Situational analysis provided the means for incorporating my prior knowledge: “Part of the process of making situational maps is to try and get such information, assumptions, and so on out on the table and, if appropriate, into the maps” (Clarke, 2005, p. 85). Problem-centered interviewing is based on similar premises: “Metaphorically speaking, the pollution of the field by the researcher’s prior knowledge is, after all, inevitable. Not making use of this prior knowledge would essentially deprive us of the learning process and the chance to discover something novel” (Witzel & Reiter, 2012, p. 24). The first batch of situational maps explicating my prior knowledge did not follow strict methodological guidelines, but was inspired by the concepts of both messy and ordered situational maps. These sketches also included assumptions regarding the relationships between actors.

I mapped the following subjects:

- The involved project partners as well as their responsibilities and activities
- The infrastructural components of the test operation
- The subsystems of the automated driving system
- The human-machine interface of the buses and the interactions between the ADS, the operators, passengers, and other road users
- Local mobility and smart city infrastructures

After completing these maps, I was prepared for the next step in the explorative phase: autoethnographic fieldwork in Seestadt.

The motive behind my visits to the district was to renew my memories of past experiences with the test operation. As preparation for the interviews, I wanted to document the

3. For a university assignment, I interviewed one of the operators before the start of this research project. I guaranteed that I would not use the content for any other purpose than the assignment. I adhered to this agreement. However, some of the insights were publicly available or got repeated in the interviews conducted for this study.

atmosphere of the Seestadt quarter, the infrastructural elements of the test operation, and the experience of riding the AVs. A prime objective was to discover the relevant non-human actors of the network. The maps containing my prior knowledge supported this process, as they revealed gaps in my understanding of the test operation that fieldwork could fill. Altogether, I conducted four sessions of fieldwork: two times in November 2020, which generated most of the material, one time in April 2021 while interviewing one of the operators, and a last time in July 2021 after the test operation was demolished. Pandemic prevention measures in Austria did not prevent fieldwork, but made it more strenuous and limited. It was difficult to get a sense of community life, as any form of hospitality was prohibited and there were fewer people on the streets. Also, social distancing conventions likely contributed to the fact that I barely encountered other passengers using the buses during data collection for this study.

The collected data and experiences formed the basis of the autoethnography presented in chapter six. As Neumann (1996) aptly summarizes, autoethnography combines two different perspectives on the relationship between the self and culture: On the one hand, it comprises an "*ethnographic impulse* that looks outward, at worlds beyond" one's own; and on the other hand, it is defined by an "*autobiographical impulse* that gazes inward for a story of self" (1996, p. 173). In a similar vein, Ellis et al. (2011) describe the method as follows: "Autoethnography is an approach to research and writing that seeks to describe and systematically analyze (graphy) personal experience (auto) in order to understand cultural experience (ethno)" (2011, p. 273). The ethnographic and the autobiographical impulse form a dialectic relationship, meaning that the one always relates to the other. Autoethnography tries to incorporate this tension, producing an inevitably subjective, embodied, and situated account of the world. Thus, this approach synergizes with Clarke's (2005) strategies for conducting grounded theory after the postmodern turn.

Marak (2015) picks up two dominant questions shaping the current discussion of autoethnography as ethnographic method: Is all ethnography also about the self and is all autoethnography also ethnography? For this study, I answer both yes and no: I observed myself as I observed others and the world around me. I strolled through the district, followed the non-human actors along the route of the buses, searched for the infrastructural elements of the test operation, rode the shuttles, and talked to people. While doing so, I focused on how I perceived the actions of the heterogenous actors in the situation. I directed my gaze both inwards and outwards, but I always remained the central point of reference. Therefore, I argue that the collected data is valid primarily as autoethnographic data, but that it also encompasses ethnographic observations. However, these observations are limited to my own sentiments and experiences.

Building on Moretti's methodological considerations, walking was the primary way of conducting fieldwork: "As an embodied, social, and imaginary practice, walking can be a way of telling, commenting on, performing, and creating both stories and places" (2017, p. 95). Taking inspiration from multi-sited approaches to ethnography (Marcus, 1995), I followed the actors of the test operation across different locations in Seestadt and beyond, trying to trace their associations across different times and spaces. Similar to how the auto.Bus Seestadt research project reassembled the urban space of Seestadt for the test of the AVs, I constructed my own perspective on the quarter through walking and riding the buses. The gathered experiences were captured through photographs, short videos, and voice memos. Although I initially tried to code the collected data using software, I quickly realized that this approach did not work for me. Managing large photo libraries in atlas.ti proved to be cumbersome, and coding already self-reflective voice recordings produced little insights beyond what was being said. The data was immensely useful in a different way: It provided me with visual proof of the network, its actors, and the interactions that enabled the automation of transport. My audio recordings from fieldwork contributed to analytical memo writing later on. All in all, the autoethnography helped me to understand the practicalities of the test operation and the collected data made it possible to compare and verify statements from the interviews.

5.3 Interviewing the Project Partners

After the first two sessions of autoethnographic fieldwork in Seestadt, I moved on to sample potential interview partners. The goal was to represent a variety of different perspectives from the project partners. Based on these accounts, I would distill an overall story of the implementation process while also highlighting different positions inside the project consortium. There are many methodological approaches to qualitative interviews (Gubrium, Holstein, Marvasti, & McKinney, 2012). For this study, I employed the concept of the problem-centered interview as developed by Witzel and Reiter (2012). I also used grounded theory guidelines (Charmaz & Belgrave, 2012) and the map-making exercises suggested by situational analysis to organize the data collection and analysis as an iterative and comparative process.

The PCI heavily relies on the metaphor of the researcher as well-informed traveler: "They [the interviewers] have certain priorities and expectations and start the journey on the basis of background information obtained beforehand" (Witzel & Reiter, 2012, p. 2). This deductive moment does not negate a strong emphasis on openness towards empirical findings – the inductive moment. Simply put, the researcher enters the interview situation well informed while focusing on the dynamic meaning making process of open dialog. The central goal of the PCI is to reduce the gap between the researcher's prior knowledge and the respondent's practical knowledge.

This goal is achieved through the principles of problem centering, process orientation, and object orientation. Problem centering is directed towards the problem addressed by the research and aims to explicate the subjective influence of the researcher on how the studied phenomenon is approached. Building on the autoethnographic data and the maps created in the exploratory phase, I further explicated my prior knowledge of the auto.Bus Seestadt project through messy and ordered situational maps (Clarke, 2005). While messy maps try to capture as many human and non-human actors as possible that matter in the situation, the ordered versions sort the actors of the unorganized map into general categories, among them: temporal and spatial aspects, individual and collective actors, discourses, political and economic factors. I also developed additional categories that fit my case, focusing on the non-human actors that were integrated in the buses and the infrastructure of the test operation.

Returning to the principle of problem centering, another important aspect is the use of sensitizing concepts. "These concepts are elastic and open to revision because of their general, empirically not contentful nature" (Witzel & Reiter, 2012, p. 25). I created a visual sketch of the concepts adopted from ANT for this purpose. This visualization provided an overview of how I would approach the empirical findings on a theoretical level.

The principle of process orientation relates to "the stepwise and flexible production and analysis of data" (Witzel & Reiter, 2012, p. 27), which positions the PCI in close relation to grounded theory. Inductive and deductive steps are iterated throughout the research process. Even during the interview, pre-interpretations are produced and revised, laying the ground for future analysis. And finally, the design and implementation of the PCI should be oriented toward the studied object, making it a flexible approach that I adapted to my specific needs.

The interview situation itself focuses on narration and strives for interactive dialogue between the interviewer and the respondent. Therefore, a question-answer scheme should be avoided at all costs. Instead, the interviewer "invites the respondent into a joint process of reconstructing his knowledge" (Witzel & Reiter, 2012, p. 32). The use of a topical interview guide is recommended to facilitate the reconstruction of the discussed problem in relation to the sensitizing framework. I oriented the guides used for this study towards the scheme by Witzel and Reiter (see figure 3.4, 2012, p. 52). A broad opening question is supposed to spark a long opening statement by the respondent. I used the following question in different variations: "Tell me about how the project and the test operation came about. What was the process like?" Relating back to the content of the opening statement, the interviewer then discusses specific topics to deepen one's understanding of the research object, answer the research question, and fill in gaps in the collected data. I tailored the discussed topics to the individual interviewee and the role of the organization that he or she is part of. With slight alterations, the following areas were included:

- The general aim and organization of the research project
- The specific role of the individual and organization in the project consortium and the cooperation with other team members as well as third parties
- The technology of the autonomous buses
- The infrastructure of the test operation and the relationship to Seestadt
- The experimental character of the project and the routine of operating AVs
- The users and passengers of the buses
- Security and safety
- The capabilities of the automated driving system and the results of the project as a whole
- Future perspectives on the potential of automated shuttles and automated driving in general

Regarding the sampling of interviewees, I prioritized the participation of representatives from the Austrian Institute of Technology and Wiener Linien, as these institutions took on leading roles in the project. Once I established contact with persons from these organizations, I asked for hints regarding other potential interview partners. This strategy proved successful, resulting in four interviews with one representative from each of the following project partners:

- The AIT, who acted as scientific leadership and used the test operation to pursue different research interests.
- Wiener Linien, who acted as project leadership and handled the practical aspect of operating the AVs in Seestadt.

- The aspern.mobil LAB, who is not part of the project consortium but supported the partners occasionally, primarily regarding the communication with locals.
- The KFV, who was responsible for public relations and the dissemination of results. The association also consulted the consortium in questions of road safety and legislation.

I also conducted a fifth interview with one of the operators from Wiener Linien. Even though the sample size was limited, the interviews provided sufficient data to answer the research questions in a detailed and precise manner. The participants told similar stories of how the project developed, which made the verification of findings possible. They also provided sufficient information on the other partners to complete the picture. With more time and resources, interviews with personnel from NAVYA could have yielded additional insights, but I decided to focus on the organizations located in Vienna.

Due to time constraints and chance, four interviews were conducted in February 2021. The tight schedule left little room for analysis in between conversations. Nevertheless, I was able to reference statements and open questions from previous interviews, allowing for a limited degree of theoretical sampling. In addition, I interviewed one of the operators in the garage of the shuttle buses approximately two months after the first batch of interviews. This time, I systematically filled gaps in the preliminary analysis. Combined with the ethnographic aspects of the interview situation, which included a tour of the garage and a private ride in the AV, this conversation greatly improved the quality of my findings. It also framed the overall research process, which started with a practical examination of the test operation and ended with my last and very special ride in one of the autonomous buses, together with the operator.

Regarding the issues of ethics, confidentiality, and privacy, the case encompassed clear constraints: The auto.Bus Seestadt research project was publicly funded and frequently reported on by both the partners themselves and third parties. Key figures are publicly linked to the project and most of the involved persons know each other from work. Therefore, full privacy and confidentiality cannot not be guaranteed. Despite this limitation, I tried to protect the identity of my participants by not stating their name. I include institutional affiliations, as this information is relevant to my research interest. All interviewees signed an informed consent form detailing the conditions for participation, as well as how I would record, store, analyze, and use the collected data. The most important points were also communicated beforehand via e-mail and at the start of each interview. Because of the Covid-19 pandemic and the unavailability of vaccination at that time, all interviews except the one with the operator were conducted online using Zoom and recorded locally. To reduce language barriers, the interviews were held in German. Quotes from the interview data used throughout the analysis were translated into English by me, with the original statements provided in the footnotes. The research interest does not raise critical ethical issues affecting the participants, nor does it endanger their personal wellbeing. Witzel and Reiter (2012) mention loyalty conflicts as a potential problem for interviews with experts, as PCIs are interested in personal sentiments and experiences which might question the representative role of the participants. My interview partners took their affiliation and professional relationships into account, but there was no apparent conflict that demanded special attention.

Reflecting on the application of PCIs and the produced data, the chosen combination of methods resulted in an extensive dataset relevant to the research interests. A challenge across all interviews was the avoidance of a question-answer scheme, as the PCI is interested in open dialog and personal motives. The expert role of the participants led to formal conversation, especially in the beginning. The opening statements were all relatively short, as the interviewees mostly stuck to the most important facts on the project. My position as fellow academic and researcher likely reinforced these tendencies. Over time, the situation usually improved drastically, and the interviewees shared selected personal opinions and sentiments with me. One also has to take into account that a Zoom meeting between total strangers allows for very little small talk, so that mutual trust had to be built during the formal part of the interview. Therefore, the final meeting with the operator in the bus garage filled me with great pleasure, as it spoke to all senses and provided me with the first and only behind-the-scenes look into the project. It encompassed a different set of challenges: The audio recording suffered from strong ambient noise, which made transcription very hard, and I had to adapt to a new environment outside the comfort of my own apartment.

5.4 Analyzing and Presenting the Data

The next step was to edit and analyze the collected data. Transcribing around five hours and 30 minutes of recorded conversation was the greatest hurdle. I processed the interviews in their order of occurrence. I also started coding the data once the first transcript was complete and switched between transcription, coding, and conducting the next interview multiple times. This allowed for some degree of theoretical sampling, as I was able to reflect on past interviews before moving on to the next. The last interview with the operators was the exception, as it took place nearly two months after the fourth interview. In this case, there was enough time to finish the first round of coding and reflect on gaps in the preliminary analysis. Thus, the final interview answered many remaining questions and helped to verify key findings.

For transcription, I used an automated online service in combination with manual editing. The informed consent form specifically mentioned the use of online tools for this purpose. I decided for gisted transcriptions (Paulus, Lester, & Dempster, 2014), keeping almost all spoken words and forms of dialect. Utterances, intonation, brakes, and other nonverbal means of communication were not deemed important enough to the research interest to justify the additional time cost of systematic notation.

Coding is the prime means for analyzing qualitative data like the interview transcripts. As Charmaz (2006) argues, this step operationalizes two major concerns of grounded theory: "generalizable theoretical statements that transcend specific times and places and contextual analyses of actions and events" (2006, p. 46). While there are strong arguments for analog coding using hard copies (Johnny, 2009), I quickly ruled out this approach in favor of quantitative data analysis software. Relying on paper seemed inefficient because of the large amount of data and the inability to quickly search and edit quotes and codes. Among the popular commercial products, I used atlas.ti due to its modular user interface.

Among the different grounded theory strategies to coding, I predominantly relied on process coding during the initial coding phase (Charmaz, 2006; Saldaña, 2011). As the name implies, I tried to "look closely at actions and, to the degree possible, code data as actions" (Charmaz, 2006, p. 48). I went through the transcripts and tried to label statements that describe actions or are performative by themselves. I used the gerund forms of verbs as labels. Focusing on actions performed by actors fit the employed ANT concepts and my interest in the implementation process. This approach to coding was complicated by the strong division of labor and the cooperation of different persons and organizations in the project consortium. Most of the time, the interviewees did not talk about individual actions performed by themselves but addressed collective actions and actors or used passive language. Therefore, it was necessary to create more abstract codes. Where applicable, I also added the collective actor who performed the described action in brackets, e.g., "[Partners]" or "[Bus]".

As soon as the codes became more robust and a significant amount of data was analyzed, I returned to the situational maps created earlier. I complemented the ordered situational maps with new actors I learned about in the interviews and refined the categorizations. This improved overview of the situation facilitated the analysis of the actor-network. I also performed a relational analysis using a situational map with the artifact of the Autonom Shuttle in the center. I posed the question of how the buses relate to all the other actors, discourses, and practices associated with the test operation, drawing lines between them. The aim of this exercise then was to "specify the nature of the relationship by describing the nature of that line" (Clarke, 2005, p. 102). Performing this analytical exercise was especially helpful for answering the second subquestion and for describing the chain of automation in subchapter 6.4.

After all transcripts were coded at least one time, I moved on to focused coding. I tried to refine the existing codes, merge similar ones, and sort them into groups. These groups made up the themes that in return informed the analysis and discussion of results in chapter six and seven. While working on the codes, I often returned to the data collected during fieldwork to link the selected quotes and codes to what I experienced in Seestadt. The aim of these comparisons was to find answers to the research questions and identify gaps that could be closed by the last interview with the operator or existing data sources. I captured these reflections through a small number of analytical memos that formed the basis of the analysis. While the coding almost exclusively focused on generating inductive insights using the empirical data, during memo writing, I brought in ANT as a deductive theoretical framework to develop the final theoretical constructs of my study. This way, I made sure that I applied the sensitizing concepts in a way that is grounded in the empirical data, instead of shaping the data to fit the theory.

The last step of the empirical process was to decide on how the results would be presented and discussed. I replicate the research process in the structure of chapter six: I start each analytical building block with a detailed ethnographic description, offering my subjective perspective on the test operation. By giving readers the opportunity to identify with my situatedness and imagine themselves in interaction with Seestadt and the autonomous buses, I hope that my analysis of the actor-network becomes more approachable and encourages scrutiny. Each narration is followed by theoretical reflection and analysis of the described phenomenon. These parts are based on the interview data, the final codes, and themes, as well as the outlined sensitizing concepts. The presentation of results in chapter six is followed by the discussion in chapter seven. This final reflection explores the meaning of the analyzed actor-network along prominent themes in my data. The auto.Bus Seestadt research project was defined by several tensions, which will be discussed in detail:

- The AVs were capable of operating on public roads but depended on the re-assembly of Seestadt into an ideal test environment.

- The operation was limited to a potentially unreliable test while presenting a mobility offer.
- The automation technology had to be adapted to the environment and vice versa to enable the operation.
- And the different partners and supporters cooperated and shared their expertise to realize the project, with each party also pursuing its own interests.

6 Tracing the Network of the Test Operation

After explicating my methodological approach to the empirical research, I continue with the presentation of findings. The following subchapters work in pairs: Detailed autoethnographic narrations grounded in the fieldwork in Seestadt are complemented by theoretical reflections and insights from the interview data. Referencing the initial vignette, I start this chapter with a stroll along the route of the bus. While walking, I tried to recognize all the visible elements of the test operation and their relations to the Seestadt quarter. As most of the infrastructure is hidden from sight, I then bring in the other data sources and the sensitizing concepts to complete the picture and construct an overview of the networked infrastructure of the test ride. I continue with the experience of riding the buses while studying the interactions between machine, operator, and environment. The semi-automatic operation of the AVs is a prime example of the process of translation, which juxtaposes heterogeneous elements into a chain of equivalences. I try to understand the chain of automation at the heart of the test operation by tracing the corresponding translations and association across the interview and ethnographic data. In the concluding two subchapters, I reflect on an exclusive ride with the bus that took place after the interview with one of the operators. This anecdote serves as a starting point for outlining some of the key challenges and issues which the project partners faced during the implementation process.

Summarizing the course of the argument: I start with the successfully translated but somewhat delicate state of test operation and end with the process of realizing this experimental infrastructure over the course of multiple years.

6.1 Spotting Infrastructures along the Route

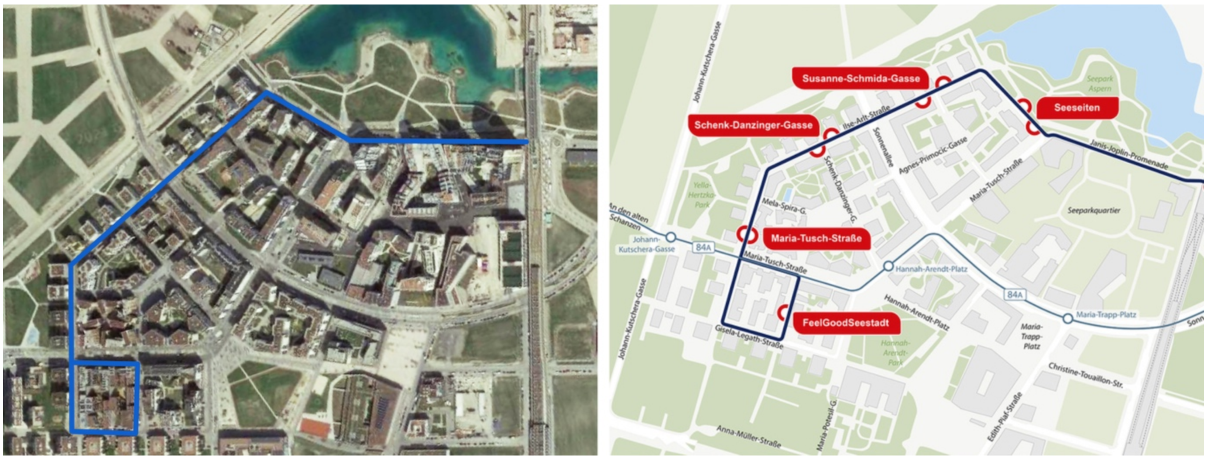

Figure IV: Overview of the route. The map on the right was provided to passengers. I added the route to a screenshot from Google Maps to give an impression of the topological features of the environment.

After my wanderings through Seestadt, I return to where my exploration started: the U2 metro Station "Seestadt" and its little sibling, the first stop of the autonomous shuttle buses. After all, the aim of the trip was to collect material on this experimental transport infrastructure. While heading for the metro station, I realize that there is a problem. On the project homepage hosted by Wiener Linien, there is a map displaying the current location of the vehicles, which I have already checked multiple times. Unfortunately, it reads: "Currently, the bus cannot be displayed"[4] I realize that there is no technical problem, but that my timing is off. The buses do not drive anymore today, because it is already past lunch. They only operate from eight in the morning to noon. After scolding myself quietly for quite some time, I decide to reframe my shortcomings as a strength: What would be a better way of studying this infrastructure than observing it without the presence of the autonomous vehicles crying for attention? I would follow Star's call to "study boring things" (1999, p. 377), namely the infrastructural elements of the test operation. Employing walking as an imaginative and ethnographic practice, I would stroll along the route of the buses to explore their infrastructural relations. Reacting to the imagination of infrastructures as "invisible, part of the background for other kinds of work" and "ready-to-hand" (1999, p. 380), I want to make visible what otherwise fades into the background. I would map the parts of the infrastructure that I could perceive through my senses while also reflecting on the

4. „Der Bus kann derzeit nicht angezeigt werden."

relations between the test operation and the built environment of Seestadt. From the existing research on AVs (Martínez-Díaz et al., 2019; Yurtsever et al., 2020), I know that automated driving depends on many different technologies, among them sensors, datasets, network connections, and algorithms. While I suspect that these aspects would be hard to recognize in the material world, I also know that smart, sensory infrastructures get embedded in the material fabric of the city to enable automations (Antenucchi, 2021; Gabrys, 2016; Graham, 2002). The bus stops seem like an obvious starting point for uncovering the infrastructure of the test operation, as they root the research project into the road network of the district.

Figure V: The first and last stop of the shuttle buses underneath the bridge of the metro station.

I take a look at the first stop located in the shadow of the metro station. The first thing that catches my attention is the design of the pole: It looks fancy and modern. In comparison, most of the other stops in Vienna look dated. They normally comprise a round pole, a semi-circular sign, and fat lettering. This one is a new kind of pole for a new district. Its industrial design is defined by sharp angles and straight lines. The stop is in line with the new design that will be rolled out across

Vienna in the next years (Wiener Linien, 2021a). The name of the stop is displayed in big letters on a horizontal sign. It does not read “AUTOBUS HALTESTELLE” like a regular stop in Vienna. Instead, the vehicle type is represented by an icon resembling the front of the shuttle buses. After examining a picture that I took, I also discovered a cone-shaped doohickey on top of the pole – a sensor of some kind? Another prominent feature of the stop is the display. I find its present to be entertaining: Of course, the stop of a futuristic autonomous bus needs to have a screen of some kind – paper behind plexiglass just would not cut it. I am even more amused by the type of display: an e-ink screen with two buttons underneath it for switching between different information. It’s like a Kindle! And it encompasses the same drawbacks as my now eight years old e-reader: The pages take a small eternity to manifest themselves.

What purpose does this display serve? Further examination reveals that it holds information on the project, the schedule, and the route. I cannot help but think that the same content would have fitted on three sheets of paper. One of my interview partners argued that the e-ink screen is easy to read. In theory, a digital monitor could also provide timely updates, but I suspect that the information hasn’t changed since the start of the test operation. Indeed, the page displaying the schedule still references the 6th of June 2019 as the very first day of operation. There’s another page accessible through the click of a button containing “The 101 of riding an autonomous bus.”[5] During fieldwork, I quickly glanced over it, but later I realized that this is a very important document. It lays out all the rules and affordances of experiment. It clearly states that it is a test operation, that it is free of charge, and that there is no replacement in case of outages. As already mentioned, the schedule doesn’t include the exact times of arrival but a time frame from eight in the morning to lunchtime. The buses only drive from Monday to Friday. When reflecting upon these conditions, I would expect exactly the opposite of a public transport service in Vienna: that it arrives exactly on time, that it has a cost attached, that it is a regular service, and that any breakdowns are mitigated as soon as possible.

5. „Das 1x1 des autonomen Busfahrens“

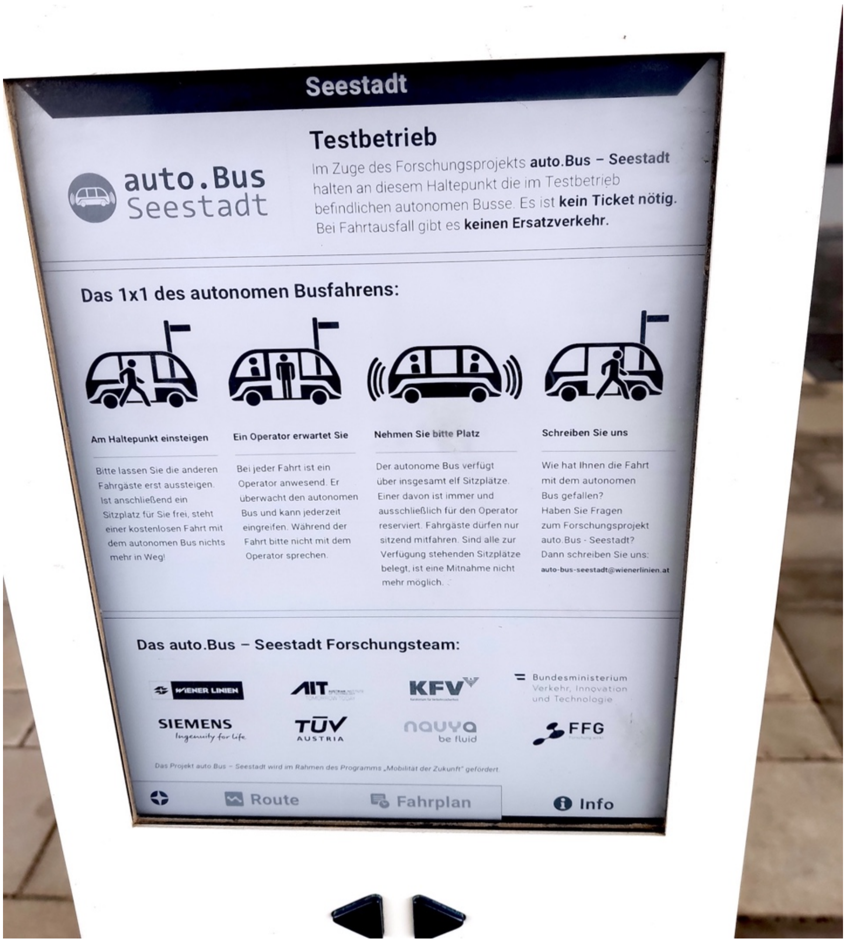

Figure VI: “The 101 of riding an autonomous bus” displayed on the e-ink screen of the first stop.

If one wants to take part in the test, there are several rules and safety precautions one has to obey: only get in at one of the stops. Let other passengers leave the vehicle first. Always stay seated. There is an operator present who monitors the bus and takes over control if needed. Do not talk to the operator while driving! Actually, I broke this rule many times. It would have been awkward not to talk to the person sitting right next to you. Also, it seemed like the employees enjoy giving information on the functions of the machine and their job. But the attention for this kind of chatter is limited, as the bus demands most of it. Safety first. The last step of the 101 is a call to participation: *Write us your feedback and questions via e-mail*. Underneath the rules, there are the logos of all the members of the project consortium. Again, this is a distinctive feature of the test operation: It is a research project and Wiener Linien as service provider is only one of many partners. Even though the operation of the AVs differs from a regular bus line in some regards, I intuitively know what to do: I would wait here at the stop for the bus to arrive and get in.

I find the detailed examination of the stops important for different reasons: They are the most prominent indicator for the practical use of this mobility infrastructure and its embedding into Seestadt. The information on the screen lays out the rules for taking part in the testing of the AVs. It also frames interested citizens in two ways: as passengers and users on the one hand, and as participants in an experiment on the other hand. The first stop of the shuttle buses strikes a balance between strangeness and familiarity. It communicates the novelty of the mobility service while offering well-known usage patterns. But onwards now!

I decide to walk along the route of the bus to get to know the environment it passes by. I follow the Janis-Joplin-Promenade, named after the US-American singer, next to the Seepark, which is park adjacent to the artificial lake that lends Seestadt its name. It's the scenic part of the route. The last time I was at Seestadt, there was a construction site and the road was blocked by a gate that the buses had to pass. This was a challenging situation for the AVs and they depended on support by the operators to resolve it. Now that it's gone, I wonder how the shuttles perform. To my left, there are modern housing blocks that define the architecture of Seestadt. I pass a dentist's office, the local adult education center, and a bookstore. The second stop is called Seeseiten, and it is indeed located next to the lake. There are stops at both sides of the road, one for each direction.

Figure VII: The smart stop equipped with IoT devices.

These again are different kinds of poles. The one on the side of the lake looks like the one I already described, but on top there's a halo-shaped device and a solar panel. It's also equipped with the same e-ink display as the first stop. While examining the halo more closely, I discover a branding by Siemens and the name OmniFlow. A quick google search yields a leaflet on this piece of technology (Siemens, 2018a). It's an autarkic Internet of Things (IoT) device for producing solar and wind energy. There's also a camera built in. After learning about the latter, I feel a little uncomfortable. The surveillance function is not obvious at all. One of my interview partners described this stop as an innovative solution that powers the display independently. I cannot get rid of the feeling that this is more of a gimmick. I imagine energy supply not to be a problem in a smart city district. The OmniFlow technology primarily seems to be a proof of concept.

The stop on the other side of the road does not have any sensors or IoT devices attached to it, it is fully analog. A sheet of paper replaces the screen, which offers similar information as the display. The digitalization of stops appears to be optional. The pole itself mostly resembles the older standard design with slight alterations: The lettering “AUTOBUS HALTESTELLE” on the semi-circular sign on top is replaced by a big white iconographic representation of the bus on red background. The pictogram of the bus is framed by wavelike shapes similar to those I know from the Wi-Fi icon on my phone. I suppose that these hint at the smart functions of the bus and its sensory capacities. Indeed, the LiDAR sensors mounted to the vehicle constantly shoot light waves out into the environment. Even though this type of stop does not encompass any digital functions, it is still demarcated from a regular bus stop. I would expect an extraordinary vehicle to arrive here.

After looking through my photographs again, there is one more thing about the stops that catches my attention: Some of them are mounted into cement and are surrounded by rectangular patches of darker, more recently applied material. This material difference makes visible that the infrastructure of the test operation was a recent addition to the district. It was only of temporary nature. As all my interview partners pointed out, in July 2021, the whole infrastructure was dismantled. The stops were ripped out of the ground and only a new layer of cement and metal covers remained.

Let’s move on then. At the end of Janis-Joplin-Promenade, the bus would turn left into Ilse-Artl-Straße. The lake gives way to the northern part of the residential area, with its large housing blocks. From now on, the stops are all analog, with either the modern or standard design. There are four more stops: Susanne-Schmida-Gasse, Schenk-Danzinger-Gasse, Maria-Tusch-Straße, and FeelGoodSeestadt, where the bus drives around the block and takes back the same route. The stops are about 200-300 meters apart, which I consider a very dense distribution. Although the bus crosses the two main streets of this area, Sonnenallee and Maria-Tusch-Straße, it mostly stays on roads with less traffic. Not that Seestadt has a lot of traffic to begin with. Along the route, there are mostly housing blocks and a few shops and businesses. While following the route, I try to recognize important local infrastructures that would be accessible with the help of the buses. Typical use cases that were explained to me, both in informal conversations and interviews, included elderly people transporting groceries and children going to school. Indeed, the last stop is close to the educational campus of Seestadt. There are also other childcare facilities like preschools along the route. Next to the U2 metro station, there is a big supermarket, so that people living along the route could use the autonomous buses to transport groceries back home. The existence of a separate supermarket building next to the central public transport station of the quarter is interesting in another regard: It is emblematic for the mixing of urban and suburban living conditions in Seestadt. If there would be a parking lot instead of bicycle racks next to it, then this scene could be located in the countryside of Lower Austria instead of Vienna.

I can think of many more scenarios in which an autonomous bus line could provide real value to inhabitants, by linking them to local businesses and services. There is not a lot of public transport operating *in* Seestadt, but mostly to and from the district. In this regard, Seestadt is structured like a small town or suburb. However, I remember how slow the buses drive, their irregular schedule (to which I also fell victim), and the fact that I have not yet witnessed any of the potential use cases in practice. There definitely is potential for the operation of autonomous shuttle buses, but in practice, this potential is not fully realized.

Figure VIII: One of the cameras used for the awareAI system.

When directing my thoughts back to the infrastructural elements of the test operation, there is one more element that I discovered: a set of cameras placed at the intersection between Ilse-Arlt-Straße and Maria-Tusch-Straße. The devices are attached to the poles of the streetlights and positioned in a way so that they should provide a full overview of the crossing. Boxes with antennas next to them hint at a network connection. I suspect that they serve the operation of the buses. Indeed, the operators and my interview partners later confirmed that the camera system informs the AVs about the incoming traffic. These infrastructure-to-vehicle communication devices are powered by Siemen's awareAI technology (Siemens, 2020; together.magazin, 2019), which uses the camera feed for different computations, among them the identification and classification of road users and the prediction of crossing times. I will elaborate on this sensing network later in the analysis.

After completing my walking tour along the route of the buses, I return to the metro station to go back home. The sun is slowly setting, and I am frozen to the bones. What have I found? Most of the artifacts linked to the test operation are not that specific to this use case: Most bus lines employ fixed stops, which might also use screens to display the schedule. Providing mobility and connecting local institutions, businesses, and other modes of transport to one another is the prime objective of public transport in general. And sensors like cameras for surveillance are already part of many public spaces. The embedding of technology into the built environment is probably heightened by the smart city approach of Seestadt. What, then, is the secret sauce of the test operation? After all, the common Viennese bus cannot drive itself, despite the existence of stops and digital sensors. I argue that there is more than meets the eye: a network of human and non-human actors that goes beyond the presented list of physical artifacts placed throughout the quarter. This network intertwines the physical and the digital sphere and participates actively in the automation of driving. I traced some of these associations, but my perspective is limited to my senses, my cold feet, and the time and place of a November afternoon.

6.2 Reassembling Infrastructures for Automation

During my stroll along the route of the buses, I conducted a first survey of the elements that made up the infrastructure of the test operation. Next, I will try to complete the picture with the help of the interview data and the sensitizing concepts. The first challenge is the very notion of infrastructures. In the previous subchapter, I simply assumed that there is a distinction between the buses and the infrastructure embedded in the built environment of Seestadt. This infrastructure would form the precondition for the operation of the AVs. I tried to recognize the various elements of the test operation while considering that, from an ANT perspective, the network would go beyond a list of technological artifacts. This approach raises multiple questions: What constitutes an infrastructure, how can it be delimited, and how does it relate to the notion of the actor-network?

As Star (1999) highlights, infrastructures are mostly taken for granted and become almost invisible in use. They are "ready-to-hand" (1999, p. 380) and thought of as substrates: "Something upon which something else 'runs' or 'operates'" (Star & Ruhleder, 1996, p. 112). These substrates would fade into the background as one focuses on the actual task. According to this notion, the infrastructure of the test operation formed the basis of driving automatically through Seestadt. But what is perceived as substrate or background very much depends on the perspective: For the project partners, the implementation and maintenance of the test operation was the actual task. The operators took on a mediating role, as they supervised the interaction between the buses and the infrastructure. Rather than conceptualizing infrastructures as static and preexistent, Star and Ruhleder argue for a relational approach: "Analytically, infrastructure appears only as a relational property, not as a thing stripped of use" (1996, p. 113). This conceptualization allows for an investigation of the test operation in relation to the practices associated with it, as well as to Seestadt as its location.

My fieldwork revealed that the operation was rooted in the built environment of the district: The stops clearly marked the route of the buses. It connected residential buildings, local businesses, and public institutions. The AVs were also part of the local mobility infrastructure, potentially bridging different modes of transport. Seestadt, the research project, and the test operation were intertwined. Besides its physical presence, the test operation also constituted a digital infrastructure. It encompassed network connections, sensors, data collection practices, computations, and digital interfaces like screens. This dimension of the test operation was linked to the quarter's status as the proclaimed smart city development region of Vienna. The integration of Internet of Things (IoT) devices into the urban environment is central to the smart city approach (Antenucchi, 2021; Kitchin, 2014). The data produced by sensors and digital networks would result in “a single view of the city” (Antenucchi, 2021, p. 80), enabling the analysis of urban processes and their automation. Gabrys (2016) describes the interplay between forms of ubiquitous computing, smart city infrastructures, and digital technologies as follows:

> Ubiquitous computing remakes cities, rather than displacing or virtually representing them, by generating considerable amounts of data to manage urban processes, as well as by directly embedding devices in urban infrastructures and spaces. (2016, p. 188)

Thus, the infrastructure of the test operation affected both the physical and digital dimension of Seestadt and reshaped life at the district in multiple ways. Another way of making sense of these relations is to conceptualize the test operation both as a network and as having been part of other networks. Graham’s notion of networked infrastructure provides a fitting theoretical basis for doing so. Networked infrastructures “bring heterogeneous places, people, buildings and urban elements into dynamic relationships and exchanges which would not otherwise be possible” (2002, p. 11). They form “sociotechnical hybrids that support the construction of multiple materialities and space–times” (2002, p. 185).

For the case of the test operation, this means that it neither formed a universal fabric that covered all of urbanity, nor that it was limited to discrete points on a map. Rather, it presented a sociotechnical process that reassembled heterogeneous actors across multiple spaces and times: It connected locations along the route during its operational schedule. Points of interest, like the lakeside, the educational campus, and a plumber’s office, were reassembled into vicinity despite their distance in Euclidian space. With the help of sensors and network connections, certain areas and processes could be monitored from anywhere in real time, like the junction between Ilse-Arlt-Straße and Maria-Tusch-Straße, the area surrounding the OmniFlow-equipped stop, and the current location of the buses. The test operation also fostered new kinds of relationships between citizens, technologies, and the built environment: Just like I did during fieldwork, pedestrians could derive information on the AVs by using digital screens, take part in the experimental setup by using the buses, and check the availability of the service on the webpage. As Gabrys highlights, such modes of participation integrate citizens into smart city infrastructure and computational processes:

> The citizen is a data point, both a generator of data and a responsive node in a system of feedback. The program of efficiency assumes that human participants will respond within the acceptable range of actions, so that smart cities will function optimally. (2016, p. 196)

An example of this conceptualization is the 101 of autonomous driving that was displayed on the screens of the stops. It told passengers how they should interact with the vehicles, enrolling them in the reality of the smart infrastructure. This restructuring of actors across spaces and times was similar to the dynamic of actor-networks, as described by Latour: "The notion of network helps us to lift the tyranny of geographers in defining space and offers us a notion which is neither social nor "real" space, but simply associations" (1996, p. 371). Thus, Graham's concept of networked infrastructure and ANT are closely related, with the former building on the latter.

After having established the theoretical basis for approaching the infrastructure of the test operation, I will analyze the corresponding artifacts and associations in more detail. As Latour makes clear, actor-networks are not limited to technical components: "A technical network in the engineer's sense is only one of the possible *final* and *stabilized* states of an actor-network" (1996, p. 369). In a similar vein, Gabrys argues that "making a list of sensor-based digital infrastructure does not necessarily address the distinct ways in which these technologies concretize in and with new environments and environmental conditions" (2016, p. 262). So rather than limiting the test operation to a static inventory of technical parts, I conceptualize it as a relational, networked, and smart infrastructure. The analysis focuses on its spatio-temporal impact and the different actors that were associated with the network.

As a starting point, I want to return to a question raised during ethnographic work: What differentiated the infrastructure of an autonomous bus line from a conventional one? The interviewee from the aspern.mobil LAB highlighted that automation creates new, more complex infrastructural demands:

> There is a whole series of infrastructural and operational considerations behind this. And this is what makes the bus special compared to a bus with a normal driver in it. He would see that the tank is empty and plan his route accordingly, so that he can gas up in the evening or something. So in this case, it is all about automation, also in relation to maintenance and such things.[6]

6. „Da steckt ja schon ein ziemlicher Rattenschwanz an Infrastruktur und so dieser, dieser Betriebsüberlegungen dahinter irgendwie. Und des macht glaub i den Bus dann a nochmal besonders im Vergleich zu am Bus, wo a Fahrer drinnen sitzt, der sieht der Tank is leer und, ja, plant das halt in seiner Routenplanung an, dass er dann halt am Abend dann nochmal aufgetankt wird

The main takeaway is that for the automation to work, the infrastructure routinely carried out work that was previously performed manually and on demand by human actors. In addition, the automation technology itself had to be maintained. To fulfill these requirements, new infrastructural relations had to be built. What exactly did this entail? Across the different interviews, a similar cast of actors and associations was discussed. The respondent from Wiener Linien summarized:

> The roads were already there. And it was all about finding an optimal route for the bus. There were also restrictions in the sense that we said: Okay, the route may only be three kilometers long, I think, because otherwise the computing power of the bus would not be sufficient. That means that we have to find a route that is three kilometers long and makes sense. In addition, as I have already said, these are electric vehicles, which means that they also have to be charged. That means we had to create two garages for these two buses. In addition, of course, all the necessary stops. And what was also necessary was a GPS antenna directly on top of the subway station Seestadt, in order to give the bus an additional signal, in order to be able to locate itself better and more precisely.[7]

This account includes elements that were already mentioned in my ethnographic account, but also previously unknown actors. During my tour, I mostly focused on the stops and the route as important aspects of using the buses. The statement raises further issues I did not reflect upon: The proximity of the stops and the overall short length of the route can be attributed to the limited computing power of the automated driving system. Within these constraints, a route had to be found that “makes sense”. What considerations lead to the final route for now remains an open question that will become clearer throughout the analysis. Besides the stops, there was another key location to which the buses were connected to: the bus garage, which was a small garage inside the garage for Wiener Linien employees, located underneath the bridge of the metro station in Seestadt. As the researcher from the AIT explained, this infrastructure was required for the maintenance of the AVs:

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oder so, ja. Also da geht’s ja viel um Automatisierung, auch in dieser ganzen Wartung und von diesen Dingen, ja.“

7. „Es waren die, waren die Straßen da. Und da ging es eben darum, eine optimale Route für den Bus zu finden. Da gab es eigentlich auch Einschränkungen dadurch, dass man gesagt hat: Okay, es sind, ich glaub, drei Kilometer lang darf diese Strecke sein, weil sich’s sonst von der Rechenleistung nicht ausgehen würd vom Bus her. Das heißt, da musst ma halt eine drei Kilometer lange Strecke finden, die da mal Sinn macht. Zusätzlich, ich hab schon gesagt, es sind Elektrofahrzeuge, das heißt, die muss man auch laden. Das heißt, wir hatten dann quasi zwei, zwei Garagen für diese beiden Busse schaffen müssen. Zusätzlich natürlich die ganzen Haltestellen, die dann notwendig waren. Und was auch notwendig war ist direkt auf der, auf der U-Bahn Station Seestadt eine GPS-Antenne, um einfach ein zusätzliches Signal dem Bus zu geben, um sich besser und genauer verorten zu können.“

> Yes, normally this happens in the bus garage, but the bus garage in Floridsdorf is too far away to let the buses drive back and forth every day. And that's why they built a small bus garage there just for the shuttles, so that they are protected, so that they can be charged, so that they can be cleaned.[8]

By creating a separate maintenance infrastructure solely for the AVs, the distance between the garage and the start of the route, the capacity of the batteries, the length of the actual route, the placement of stops, and the operational schedule were all matched properly. Taken together, these compromises already led to a strongly delimited operational design domain of the buses (SAE International, 2021). As Stayton and Stilgoe criticize, the conceptualization of the ODD by the SAE "externalizes much of what is most important to the operation of real-world systems" (2020, p. 17), like practical and technological limitations of the implementation.

Another element I did not recognize during fieldwork is the GPS antenna on top of the metro station. This sensor was critical for the functioning of the automation technology but remained invisible to the uninformed eye. Its existence underlines the networked nature of the test operation and the complex restructuring of time and space: It referenced the buses' location to the fixed coordinates of the antenna and the satellites of the global navigation satellite system (GNSS) in the earth's orbit. The interlinking of these distant locations and objects presented another requirement of the automation technology, as the operator explained:

> The GPS of the vehicle would be too inaccurate, because with the GPS you get a maximum of 40 cm accuracy and when I drive in traffic, passing parked vehicles, 40 cm to the left or 40 cm to the right, that won't work out. That's why we have a base station on top of the station's roof. It must be in the vicinity of the bus line so that it reaches the base station.[9]

The use of a reference antenna in combination with GNSS and IMU technology integrated into the vehicle is called Multi-GNSS RTK tracking (Sun et al., 2017). The same technique was employed for the test of a NAVYA shuttle in Koppl, Salzburg (Rehrl & Zankl, 2018). In Seestadt, the proximity between the base station and the vehicles was an important

8. „Ja normalerweise passiert das in der Busgarage, aber die Busgarage in Floridsdorf ist zu weit weg um da die Busse hin und her fahren zu lassen jeden Tag. Und deswegen hat man dann dort eine kleine Busgarage nur für die Shuttles hingebaut, damit die geschützt sind, damit sie aufgeladen werden können, damit sie gereinigt werden können."

9. „Da aber das GPS ja zu ungenau wäre am Fahrzeug, weil da, mit dem GPS kommt man maximal auf 40 cm Genauigkeit und das aber, wenn ich im Straßenverkehr fahre, an Parkenden vorbei, 40 cm links oder 40 cm rechts, das wird sich nicht ausgehen. Deswegen haben wir eine Basis-Station, oben am U-Bahn Dach. Die muss halt in der Umgebung sein von der Linie, dass es die Basisstation erreicht."

consideration for the design of the route and the placement of stops. As the addition of the bus garage and the antenna show, the relationship between the district and the test operation was in part determined by technical limitations of the employed vehicles. In order to implement the networked infrastructure of the test operation into Seestadt, associations between the existing and newly added infrastructure had to be formed. The reliance of the ADS on infrastructure networks underlines a point made by Stayton et al.: "The more automated the system is, the more interconnected it must be with vast networks of humans and machines outside the individual vehicle, which must be trusted to operate appropriately" (2017, p. 101).

There is another feature I described in the previous subchapter that depended on GPS and the current location of the buses: the live representation of the vehicles' location on the Wiener Linien homepage. This seemingly gimmicky service highlights the general importance of localization for the test operation while also exemplifying the involved challenges on a technological as well as usability level: Because the service neither followed a strict schedule nor was replaced in the case of an outage, it would have been impossible to know whether and when a vehicle arrived at a certain stop. Therefore, monitoring the current location of the buses in real time was not only essential for the functioning of the AVs but also potentially useful for passengers – as long as the live map worked and the users knew about its existence. The synchronization of the physical location of the buses with their GPS coordinates and their location on the two-dimensional map is an outstanding example of the intertwining of various networked infrastructures and the ability of actor-networks to reshape space-time relations in complex ways. The tracking of vehicles in real-time is also a typical use case for intelligent transports systems (Kitchin, 2014) and acts as a proof of concept for Seestadt's smart mobility infrastructure. In practice, the interconnections between different places also led to conflicts uncertainties: The live feed involved quite a bit of latency and it might have been unclear whether the location of the buses on the map was not available because they were not operational or because the system was out of order.

Unfortunately, I failed to reflect on this feature with my interviewees. But there was yet another instance of location-tracking that was discussed on multiple occasions: the network-connected cameras powered by Siemen's awareAI technology (2020) at the junction between Ilse-Arlt-Straße and Maria-Tusch-Straße. In contrast to the previously discussed localization practices, this sensory infrastructure was not focused on the shuttle buses but directed towards all other moving entities: It detected and classifies road users and tracked their movements in relation to predefined zones, like crosswalks and traffic lanes. The AIT researcher explained its purpose as follows: "Then in the infrastructure, [we] also anchored corresponding sensors, which help the bus to look around the corner, so to speak, so that he does not have to brake abruptly if he realizes too late that there is someone coming."[10] In a similar vein, the representative of Wiener Linien described these sensors as "additional infrastructure" that told the ADS whether the road was free or not. Indeed, a news article in Siemen's in-house magazine states that the computations performed by the awareAI system were communicated to the bus via a proprietary protocol (together.magazin, 2019). The addition of this experimental infrastructure-to-vehicle communication infrastructure was a first step towards cooperative and connected automated driving, which is still in its infancy (Martínez-Díaz et al., 2019; Yurtsever et al., 2020). It also highlights the interconnection between the sensing network of the test operation and Seestadt's smart city infrastructure: In theory, different sensors and automations could reinforce each other, allowing for a technology-induced real time view of city processes (Antenucchi, 2021; Kitchin, 2014). However, the additional data provided little benefits to the operation, as the analysis will show.

The interviewees' statements on the camera system underline Star's argument that "one person's infrastructure is another's topic, or difficulty" (1999, p. 380). For the researcher from the AIT, the urban environment presented an infrastructure for the deployment of additional sensors. For both the respondents from the AIT and Wiener Linien, the surveillance system at the junction was a supportive infrastructure that helped the buses to drive automatically. Rather than giving in to the question of perspective – what counts as infrastructure or substrate, what as actual task or practice – I want to return to the argument that the infrastructure of the test operation was both relational and networked: It associated multiple systems, infrastructures, and practices with one another, creating a combined network. As Graham argues with reference to ANT:

> Actor network theory thus also undermines the notion that we can simply and unproblematically generalise a single material 'thing' called an infrastructure network, just as it challenges the idea that we can simply generalise a city. Instead, sociotechnical worlds emerge as a continuing cacophony of endless flux and fragile, multiple interdependences. (2002, p. 186)

10. „Dann eben in der Infrastruktur, dann [haben wir] auch entsprechende Sensoren verankert, die dem Bus helfen quasi um die Ecke zu schauen, damit er dann nicht abrupt abbremsen muss, wenn er erst zu spät draufkommt, dass da, dass da jemand daherkommt."

The main takeaway is that infrastructures, cities, and urban life coproduce each other through sociotechnical processes. Instead of insisting that there is a single city represented on a single map containing a fixed number of clearly differentiated entities, from an ANT perspective, urban reality becomes multiple. The notion of the urban assemblage captures this multiplicity: "It allows and encourages the study of the heterogeneous connections between objects, spaces, materials, machines, bodies, subjectivities, symbols, formulas and so on that 'assemble' the city in multiple ways" (Farías, 2012, p. 14). From this perspective, the auto.Bus Seestadt project assembled the district in a specific way.

I already highlighted some of the interrelations between the quarter, local infrastructures, and the specific infrastructure used for the autonomous shuttle buses. Because of the temporary and supplementary nature of this networked infrastructure, existing constellations were rearranged to make room for the AVs. Next, I will elaborate further on how the auto.Bus project reassembled Seestadt throughout the implementation of the test operation. How was Seestadt enacted in this case? What was the meaning of the quarter for the test operation? How did the networked infrastructure and the city coproduce each other?

Both my ethnographic experiences and the interview data revealed that the route was the most important interface between the test operation, the built environment, and community life. The route reassembled the topography of Seestadt by connecting disparate locations and practices associated with them. It already became clear that decision on the route was not arbitrary: The project partners were looking for a version that "makes sense". It made sense for them to consider GPS reception, charging ports, and computational power as important factors. Still, there would have been innumerable options for designing the route. As the researcher from the AIT explained, there was yet another set of criteria that influenced the final decision:

> We made sure that one could test as many different traffic situations as possible on the test track. So you have an unregulated intersection. You have a traffic light-controlled intersection, you have crosswalks. Yes, so there are many different situations where you can test different behaviors of the bus.[11]

11. „Und so hat man halt dann geschaut, dass man auch auf der Teststrecke so viel wie möglich an, sag ich mal, unterschiedlichen Verkehrssituationen auch testen kann. Also man hat eine, eine ungeregelte Kreuzung drinnen. Man hat eine ampelgeregelte Kreuzung drinnen, man hat Zebrastreifen drinnen. Ja, also sehr viele unterschiedliche Situationen, wo man dann auch verschiedene Verhaltensweisen des Busses testen kann."

This excerpt shows that, besides the technical requirements of the vehicles, the research interests of the project partners also played an important role. Including diverse traffic situation in the route allowed for better testing of the automation technology. I will elaborate on how the AVs responded to these challenges in subchapter 6.4. The project partners took in the position that the AVs should adapt to the local traffic conditions. They expected them to live up to the demands of reality just like any other road user would need to do. Correspondingly, the test operation assembled Seestadt as a road network that acted as a testing ground for the automation technology.

The operator underlined that, for Wiener Linien, the design of the route and the operation of the shuttles was about adaptation as well, albeit in a different sense:

> This main road through there, through Seestadt, where the bus goes through. We would have blocked our bus there. We said that we can't drive through there, besides, the big bus is going anyway. And then we looked for an alternative, how we could drive.[12]

In this statement, Seestadt is assembled as a public transport network that covers certain roads and areas. For Wiener Linien, it was important that the test operation did not interfere with the existing network, but there is also the implicit assumption that the shuttles acted as a supplement, covering new areas. All of my interview partners reflected on this potential by using similar arguments: Currently, the local public transport infrastructure would be of relatively low quality – with great improvements already on the way. The buses would have filled a temporary gap by transporting passengers back and forth between the housing blocks and the metro station. As the operator put it: "Yes, the subway is very important. And there's simply nothing driving back there, so you can have these little feeders to the houses, if you drive around there. The regular bus goes right through the middle of it anyway, and we take this route."[13]

These arguments construct Seestadt according to the logic of commuting, as a place of departure and return. The shuttles would have acted as a non-disruptive, supportive addition to the urban transport infrastructure. This narrative is in part contrasted by the temporary nature of the project. The operator emphasized: "And after those three years,

12. „Die Überlegung war, diese Hauptstraße da durch eigentlich, durch die Seestadt, wo der Linienbus durchfährt. Da hätten wir unseren Linienbus blockiert. … Ding, das haben wir gesagt, da können wir nicht durchfahren, außerdem fährt ja eh der große Bus. Und dann haben wir eine Alternative gesucht, wie wir fahren können."

13. „Die U-Bahn ist sehr wichtig, ja. Und einfach diese, da hinten fährt halt nichts herum, da kann man halt diese kleinen Zubringer zu den Häusern da hinten, wenn man das umfährt. Der Linienbus fährt eh mitten durch und wir fahren diese Runde."

when we're done, this bus will be canned."[14] Considering its relatively short lifespan, the interviewees argued that the test operation neither presented an essential mobility offering, nor that it replaced existing services. Therefore, the overall effect of the project was limited. The researcher from the aspern.mobil LAB told me that the project partners emphasized this point in communication with the inhabitants: "It's a test operation. This is no new fixed infrastructure of Seestadt, not at all."[15] Speaking from my own experience, there was no guarantee that the shuttles would be operational – even during their flexible schedule. In contrast, Wiener Linien compensates for any major service disruption of its regular public transport offerings. Thus, the implementation of the test operation into the quarter was not only framed as non-disruptive, but also as temporary and entirely optional.

However, the re-assembly of Seestadt by the research project also encompassed disruptions and alterations. The researcher from the AIT told me that there were potential conflicts of interest between the test operation and the existing car infrastructure which had to be taken care of: "It's always a big difficulty to take away parking spaces somewhere to create a stop. So, in most cases, no parking spaces had to be taken away."[16] Seestadt is a densely inhabited area that grows every day because of the belt of construction sites surrounding it. Space is at a premium. For the test operation to fit in, space had to be cleared first – even if only a small amount was required. The patches of fresh cement surrounding some of the stops made this tension apparent. Urban material had to be ripped out to make room for something new. The fact that the operation involved material changes to the quarter relates back to the paradox that more autonomy is only possible through an ever-increasing reliance on always-connected digital infrastructures (Stayton, Cefkin, & Zhang, 2017) and the definition of the ODD according to infrastructural dependencies (SAE International, 2021; Stayton & Stilgoe, 2020). Stayton and Stilgoe argue: "Self-driving vehicles will not just adapt to the world as it is; to operate effectively, the world around them will need to adapt too" (2020, p. 17). In the case if the auto.Bus project, these adaptations had no lasting impact. After the end of the test operation in June 2021, the only physical traces left were patches of fresh cement. To the untrained eye, the AVs might have never been there, even though the corresponding infrastructure was

14. „Und nach diesen drei Jahren, also wenn wir fertig sind, wird dieser Bus eingestampft, kann man sagen."
15. „Sehr, was glaub i a einfach wichtig war, da in der Runde zu klären: Es ist ein Testbetrieb. Das ist jetzt kein, keine neue fixe Infrastruktur der Seestadt."
16. „Es ist, es ist immer eine große Schwierigkeit irgendwo Parkplätze wegzunehmen, um dort eine Haltestelle zu machen. Also in den meisten, meisten Fällen ist es so, dass keine Parkplätze weggenommen werden mussten."

inscribed on the material fabric of the district.

Seestadt was not only reassembled on the physical level but also on the digital. As argued previously, the practice of localization and the reproduction of physical space by digital means were key to the infrastructure of the test operation. The live map available to users on the project homepage was only a minor aspect of the performed translations, as the automation of the buses relied on far more complex data: With the help of the GPS tracking, the buses could locate themselves. Still, this data alone would have been insufficient. In order to precisely follow the route through Seestadt, the AVs required information about their environment as well: three-dimensional, topographic data. To provide this information, NAVYA created a detailed scan of Seestadt. The operator explained this process as follows:

> Then comes NAVYA. They drove around with a car similar to the Google car. Exactly, they mounted it [the necessary technology] onto the roof, they rented a car, mounted it onto the roof, and drove along the route. They measured the route together with the whole environment.[17]

The same technique was used in the Digibus project in Salzburg (Rehrl & Zankl, 2018). With the help of LiDAR sensors, NAVYA engineers translated the environment alongside the route into a digital representation containing its exact measurements. The buses used this data to orient themselves and find their way through the district. Thus, the physical and digital versions of Seestadt were intertwined and had to overlap as much as possible. Like the GPS antenna and all the other sensors of the test operation, this digital infrastructure was hard to recognize by human senses alone. As Antenucchi makes clear, the relationship between the visible and the invisible is deliberately shaped by sensing technologies:

> When sensing technologies … are applied to urban components, they enable new modalities of perception and interaction. They remodulate patterns of attention towards the object, resource or activity concerned. They can invite and even force attention from users, or, conversely, they might deliberately avoid it, when they are invisible. (2021, p. 93)

When reflecting on how the user's attention was managed by the infrastructure of the test operation, there was a clear divide between the components directed towards human actors – like the stops and screens – and the components that served the automation

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17. „Da kommt dann NAVYA, die fahren des, die sind das mit einem Auto so wie das Google Auto gefahren. Genau, die ham des [die notwendige Technologie] aufs Dach montiert, die haben sich ein Mietauto, haben des aufs Dach montiert und sand die Strecke abgefahren, diese Strecke ausmessen mit der ganzen Umgebung."

technology. The former type easily captured one's attention, while the latter was largely hidden from sight unless one explicitly went looking for it. The infrastructure of the test operation became invisible in use, especially as digital data, computations, and network connections made up a large portion of it.

Returning to Graham's concept of networked infrastructures, the effects of the test operation on Seestadt underline their potential to "support the construction of multiple materialities and space-times" (2002, p. 185). The autonomous bus line reassembled Seestadt on multiple levels: It transformed the local transport infrastructure and built environment through the placement of stops, extended the public transport coverage of the area, gave commuters a new tool at their disposal, adapted their routines to the flexible schedule, reshaped distances and relationships between disparate locations through the route of the buses, and superimposed the physical space of Seestadt with a digital reproduction of its topography. As the analysis of these reassemblies has shown, the project partners built the test operation upon existing infrastructures and networks while implementing new ones. The result was not only temporary and provisional, but also exclusive and partial.

In the beginning, I argued that the test operation was not a uniform fabric that covered all of urbanity. A close examination of this networked infrastructure revealed that it was limited to only a very small part of Seestadt and a single purpose: automating the driving maneuvers of the AVs along the route. Most of the described components and interactions were irrelevant or did not exist outside this context: The buses operated in Seestadt only. The new stops were only served by the shuttles. The GPS reference antenna was only used by the AVs. Not all of Seestadt was scanned, but only the parts alongside the route. The high degree specialization contrasts the conceptualization of infrastructures as ubiquitous systems, like it is the case with electricity or internet access in most Western metropolises. The exclusiveness of the networked infrastructure of the test operation underlines a point made by Graham on what he calls the splintering of urbanity and urban infrastructures: "Single geographies where networks bind spaces and cities are giving way to multiple, overlaid and customized grids that unevenly connect parts of cities together and to intensifying interactions elsewhere" (2002, p. 189).

As the analysis has shown, the test operation presented a customized grid designed solely for the aims of the auto.Bus Seestadt project. This networked infrastructure assembled new and existing infrastructures, networks, and actors into a specific enactment of Seestadt. The strong delimitation of the test operation made it possible to implement and dismantle this assemblage without causing major disruptions of the adjacent infrastructures and networks. In some cases, new connections to existing networks were simply cut, like the connection between GPS and the reference antenna. In other cases, components of the test operation were relatively independent from other networks, so that they could be easily removed, like the stops. Seestadt flourished before the implementation of the automated shuttles and continues to do so after their disappearance. But the continuity of community life does not mean that the test operation was pointless. But its time and scope always were limited.

Returning to Star's (1999) argument that infrastructures are commonly seen as substrates for the actual task, and to my initial assumption that there was an infrastructure that provided the basis for the operation of the AVs, the empirical data presented an ambivalent picture: I was able to identify a list technological artifacts that were associated to the test operation and could be interpreted as forming the substrate for the automated driving of the shuttle buses. But these artifacts and digital networks also have to be seen in the context of existing smart city infrastructures and the reshaping of urban space, time, and sensibilities through sensors and computations embedded in the urban fabric (Antenucchi, 2021; Gabrys, 2016).

From an ANT perspective, the distinction between the infrastructure of the test operation and automated driving as a use case that works "on top" of this infrastructure does not hold. According to Latour, ANT does not rely on the "notions of levels, layers, territories, spheres, categories, structure, systems. It aims at explaining the effects accounted for by those traditional words without having to buy the ontology, topology and politics that goes with them" (1996, p. 370). Following this argumentation, the test operation appears as a flat network of heterogeneous actors associated with the testing of AVs in Seestadt. The Autonom Shuttle was one node of this network, and so were all the other parts, like the cameras at the junction and the different types of stops. Thus, the question is not whether something or someone is part of the infrastructure or not:

> A network is all boundary without inside and outside. The only question one may ask is whether or not a connection is established between two elements. The surface "in between" networks is either connected – but then the network is expanding – or non-existing. Literally, a network has no outside. (1996, p. 372)

Throughout this subchapter, I have described a large variety of elements that were related to one another, and when taken together, formed the networked infrastructure of the test operation. The shuttle buses were connected to this network and would not have born any meaning outside its context. As the analysis has shown, they could not operate without the support by the infrastructure and vice versa: Without the shuttles driving through Seestadt, components like the stops, the GPS antenna or the three-dimensional scan of the environment would have been pointless.

In the next two subchapters, I will describe the experience of using the shuttle buses and analyze how the automation of driving worked in practice. The chaining of actor for the automation incorporated most of the infrastructural components described here.

6.3 Riding the Bus

Figure IX: Operator and bus waiting for the next round.

It is half past eight on another grey November morning. The last time around I missed the buses, so I return to Seestadt only three days later. During my commute to Seestadt, it seems like I am going in the wrong direction. The closer I get to my destination, the fewer people are left in the metro. Among those few people traveling to Seestadt, I am probably the only one who still goes there for the autonomous buses. It is relatively early, so they should be operational today. Indeed, I encounter one of the vehicles right after my arrival. The bus is parked next to the stop underneath the metro station and to my amazement, a woman just got in. On previous occasions, I rarely met other people using this infrastructure. It would be interesting to observe another passenger. Unfortunately, I am expecting an important call that I do not want to take inside the bus, so I let this opportunity slip. Instead, I keep observing the scene from afar, hoping that my prying is not too obvious. The bus starts moving and goes back into the rotary behind the metro station. The LED sign on the rear window reads "Manual Driving," so the operator inside the vehicle seems to be in control. The bus turns around and drives back to the metro station. It continues its path on Janis-Joplin-Promenade along the lakeside and slowly fades into the horizon. As already mentioned, a year ago, this part of the route was partially blocked by a construction site. It is almost finished now, but there are still a lot of heavy vehicles driving around. The LED sign of the bus tells me that this passage is also driven manually. I wonder what still holds back the automation. When the construction site and the gate were still there, the buses were at least able to drive semi-automatically, depending on only a few commands by the operator. As the vehicle slowly moves out of sight, I wonder whether I will see it again. There might be a technical issue or a sudden change in weather. I check the live map on the Wiener Linien homepage right away, only to realize that the location of the buses is unavailable. I can only hope that it will keep going. I also fear that today's operator is the same person I already interviewed about a year ago for a university assignment. It might get awkward once he realizes I am back to ask even more questions.

I have been watching the bus going back and forth along the route for quite some time when I finally receive the call. Time to get on the bus! I decide to wait at the last stop called "FeelGoodSeestadt". After a few minutes, the vehicle slowly drives around the corner. Before it comes to a halt, the bus makes two distorted-sounding signals to announce its arrival: BLINK. BLINK. There is no passenger inside, and to my relief, the operator is a different man than the one I already know. I get in, greet, and try to catalog the interior of the bus: In the back and front there are four seats facing each other. In addition, three retractable jump seats are located vis-à-vis the doors. The inside is split in half by a transparent divider similar to a shower screen. Upon closer examination, I realize that this is a self-made solution recently added as a Covid-19 prevention measure. The operator sits on one of the jump seats on the other side of the divider.

Figure X: A professional tape-job holds the Covid-19 prevention screen together. The interior felt quite cramped, and only two passengers were allowed inside the vehicle at that time.

Sitting this close to the bus driver, or operator, feels unfamiliar. There has not been a lot of room even without the divider, but now the shuttle is crammed. At least there is no second passenger, a possibility that triggers my social anxiety just by imagining it. Clearly, the bus was developed before the pandemic. Keeping a distance is pretty much impossible. In retrospect, the interior also bears resemblance to a confessional, but with wheels and transparent walls. One both feels inclined to talk and stay silent. Even more so as I wrestle with myself to tell this employee about my fieldwork. What else catches my attention? When compared to a conventional bus, a lot of things are missing: There is no steering wheel, gas pedal, gearshift, break, or blinker. The only element that comes close to the cockpit of a conventional bus is the touchscreen mounted next to the operator.

He presses a button on the screen and the doors close. After two BLINKs, we start moving with around twelve kilometers per hour. Neither I nor the operator control this movement. The bus seems to drive itself, like one would expect from an autonomous vehicle. It is easy to forget about the novelty of the situation. Sure, the driving experience is slow and sometimes jerky, but it the end it feels like any other bus ride. Stilgoe and Cohen describe this experience as the paradox of acceptance: "If the technology works, its users may be briefly impressed but quickly bored. The technology's opacity (we cannot see how or why it is doing what it is doing) make it oddly unimpressive. Its possible benefits (safety and efficiency) are almost always invisible" (2021, p. 6). While I feel safe during my ride, the operation is not very efficient. Reflecting on my expectations towards the autonomy of the bus: It should perform the given driving task automatically, but its agency should be limited to this function. I realize that this is a rather mechanistic understanding of autonomy. Today, the automation seems to perform smoothly, and I wonder whether the performance has improved since my last ride? The operator tells me that basically nothing has changed for a long time. My memories are fooling me.

But how does the automation of driving work in principle? This is the main question I try to collect material on during the ride back to the metro station. The most important observation I already made during previous rides is that the operator and the bus have to work in tandem. It is hard for me to recall the exact sequence of interactions, as the operational procedure is heavily routinized and somewhat hypnotizing to the observer. My attention slips easily while watching the interplay between the operator and the machine, but the basic sequence goes like this: The operator presses the button on the screen. This sets the bus in motion. It then drives automatically with relatively constant speed. I would bet that it steers more precisely than a human, even though it might be selective perception. It mostly just feels slow, like the vehicle never really hits the gas. During the whole ride, the operator tries to be as attentive as possible: He is always looking up and down the road, while also checking the status information displayed on the touchscreen. After a short time – I would guess that it never takes a full minute – the vehicle stops relatively abruptly. It might make the BLINK sound. Then the operator makes a full sweep of the traffic situation, by sitting up more erect or by temporarily standing up. Then he presses the aforementioned button, and the vehicle starts driving automatically again. To me, it seems like the bus constantly asks the human for permission to go on. I suspect that these interactions are in part scripted, because they happen at distinctive points along the route, like at intersections and stops. It reminds me of pasting files from one place to another on my computer: The command is performed automatically, but once in a while the operating system asks me whether I want to override an existing file or keep a copy. The computer considers this question too complex or too dangerous to make on its own, so the decision is passed along to me, the human. Hopefully, the operator knows what to do and not just mindlessly hits the button. Bainbridge (1983) discusses the increasing need for human monitoring and intervention along several ironies of automation. At first, the job of the operator might appear obsolete and laid-back – the machine does everything for him. But only after a few minutes of riding the bus, it became clear to me that the operator acts as patient and diligent guide of the automation system. Without this man, the bus would be lost.

Figure XI: After arriving at the stop, the operator pressed the button on the screen to tell the bus to continue. The photograph on the left shows the interaction between the interface and the operator on another occasion.

Things do not always go according to script: We just entered the crossing between Ilse-Arlt-Straße and Sonnenallee when the vehicle suddenly makes an emergency braking. The centrifugal force almost throws me off my seat. I am on full alert. The operator looks nervously in every direction. There is no apparent reason for this abrupt halt, the road is clear. The operator performs a variety of actions on the display and the bus slowly accelerates again. It seemed like the operator had to make some kind of error report or grant additional permissions to the bus. This interruption made me realize why all passengers have to be seated at all times and why the bus drives at such a low speed. In the case of a potential emergency situation, the AV is as uncompromising and fast as an industrial machine. It feels inhuman and a little scary. Then again, these lightning-fast reflexes probably make the bus safe enough for public roads. The vehicle would definitely come to stand before hitting other road users, even if this incoming obstacle is only an imagination of the machine.

Up to this point, I observed that the bus drives certain segments of the route automatically, and that it stops at certain points along the route and in front of potential dangers. But as the writing on the LED signs in the back and front of the vehicle already hinted, there is a third type of interaction: The operator takes over control from the automation system under certain situations. Towards the end of our ride, we return to the stop called "Seeseiten" on Janis-Joplin Promenade, next to the lake. In front of us are the remains of the construction site, and a large truck is blocking the road. Instead of telling the bus to go on, the operator waits at the stop. He does not press the button on the touchscreen. The operator then grabs a XBOX One gaming controller and maneuvers the vehicle to the metro station himself. It is funny to me that all the controls of a conventional bus are condensed into a small gamepad and that the autonomous bus at times works like an oversized remote-controlled toy car. I also wonder how the controls compare to a video game. My driving skills in Grand Theft Auto would disqualify me for this job.

The operator smoothly swerves around the truck. I rode the bus about ten times now with no major incident, so I assume it is safe and always will be. The operator seems focused, and I know he is a skilled bus driver. As we slowly reach the first and final stop underneath the metro station, I tell him about my research and ask whether I can stay for another round. He tells me I need to wait because he has to make a break now. Ironically, the operators are legally conceived as bus drivers, so they are only allowed to drive for a certain amount of time without a break. I think about how paradoxical the relationship between operator and bus is: The vehicle can drive automatically, except when it cannot and needs the operator. The operator watches the automation for hours while having to take over control at key moments, only to be limited to the role of the observer once again. The bus could continue forever if it were not for the limited capacity of the batteries, while the operator needs a break from driving even though he is not a driver. Without even going into the technical details, it became clear to me that the automation of driving is neither a simple nor a straightforward endeavor. There are a lot of different interactions at play, which I will unpack systematically in the next subchapter.

6.4 The Chain of Automation

The experience of riding the buses and observing the interaction between the operator and the machine already yielded important insights into how the automation of driving was accomplished. One of the main takeaways of my rides with the shuttle is that the operation was routinized and depended on the close interaction between human and non-human actors. In this subchapter, I will explore in detail how the automation worked and what its limits were. As argued in subchapter 6.2, the automation of driving has to be understood in relation to the infrastructure of the test operation. The vehicles, operators, and passengers depended on this networked infrastructure, so that the automation of driving cannot be separated from its infrastructural context. From an ANT perspective, the test operation presents an actor-network that “associates heterogeneous entities. It defines their identity, the roles they should play, the nature of the bonds that unite them, their respective sizes and the history in which they participate” (Callon, 1986b, p. 24). During fieldwork, I encountered a relatively stable version of this network. Most of the translations binding actors to their ascribed roles were already stabilized. But “translation is a process before it is a result” (Callon, 1986a, p. 224), and even when translations appear stable, they have to be constantly renewed. By closely examining the routine of the operation and by tracing the associations between the involved actors, I hope to understand the translations that enabled the automation of public transport. The interviews provided me with detailed insights into how the project partners and their allies conceptualized the functions of the AVs. I will combine this data with my ethnographic experiences to reconstruct the operational procedure that took place during my rides on the bus.

Callon and Latour describe how the Electricité de France, as a powerful technoscientific actor, approached the task of network building in the case of the véhicule électrique:

> It ties together all these scattered elements into a chain in which they are all indissociably linked. One is forced to go through them just as if a line of reasoning was being unfolded, a system developed or a law applied. (1981, p. 289)

The project consortium of the auto.Bus Seestadt project might have acted similarly. I want to focus on the concept of the chain, which fits my observation that the operation of the buses followed a routine that constantly got reenacted. The creation of such a chain is a constructive process that creates a particular order out of innumerable possibilities. Studying an actor-network is about understanding "'how a privileged trajectory is built' through heterogeneous processes of translation and association" (Michael, 2017, p. 41; see Akrich & Latour, 1992, p. 259). I define the order – or trajectory – of the test operation as the chain of automation. This chain coordinated the interactions between the actors to achieve the partial automation of driving. Thus, the chain of automation was equivalent to the specific implementation of automated driving functions for the auto.Bus Seestadt project. On a technical level, the modular architectural design of automated driving systems (Yurtsever et al., 2020) is similar to the relational character of actor-networks, although technical descriptions omit the social aspects of automation: The different components of the system – both human and non-human – constantly engage in reciprocal decision making processes and pass information between each other. This procedure goes beyond a static list of functions and modules.

Before exploring the translations and associations that made up the chain of automation, I start with reflecting on the expectations towards the test operation, its goals, as well as its actual performance. What did this networked infrastructure try to accomplish? What problem did it try to resolve? Thinking about these questions is important, as they lead to the problematization at the heart of the actor-network. During problematization, an actor defines a problem to which the future actor-network responds to. The posed problematization determined which actors the project partners interested in joining the network, and the roles they imagined the actors to assume. If the addressed actors wanted to be part of this reality, they had to accept the instructions of the project consortium and move to their assigned position in the actor-network. The creation of obligatory passage points (OPPs) supports problematization: "Translation thus maps out a geography of necessary points of passage for those elements who wish to continue to exist and develop" (Callon, 1986b, p. 27). Both processes work in tandem, as actors have to go through the outlined OPPs to join the actor-network. Once an actor rejects other options and takes the detour through the OPP, it gets associated with the network. In the case of the auto.Bus project, the geography of OPPs corresponded to the design of the test operation: If actors wanted to take part in the automation of public transport in Seestadt, they had to leave their previous existence behind and move into the network. "To translate is to displace" (Callon, 1986a, p. 223), and the test operation in Seestadt was the locus where all the different actors were brought together. So what was the overall goal of the network?

The most basic problematization that I can identify is: How can one make the buses drive automatically along the route? The project partners joined the efforts of all actors to resolve this problem, which resulted in the chain of automation. As my ethnographic and interview data showed, the implementation of automated driving for the auto.Bus project depended on a number of limitations and workarounds. Some of them were already touched upon in relation to the infrastructure of the test operation, while others became apparent after riding the AVs and conducting the interviews. I will explore these limits in more detail to learn about the design of the chain of automation and the problematization at the heart of the actor-network.

Despite the high expectations raised by terms like "self-driving" or "autonomous," all interview partners shared the opinion that the employed automation technology is fairly limited. The interviewee from the KFV stated:

> It's not insane performance which each of the buses accomplishes. It's kind of driving on invisible rails. And it stops at the intersection and as soon as something enters its field of vision, it also stops. I think it stops more.[18]

The operator described the vehicle's behavior in similar terms: "The vehicle cannot swerve either. It follows its pre-programmed route and if there is an obstacle on the route or in its danger zone, which is programmed, then it simply stops."[19] These statements verify the driving functions I identified during fieldwork: The bus followed a script or program similar to how a train follows the rails. At certain predetermined points, e.g., at an intersection, the vehicle stopped and awaited commands from the human operator. In addition, the vehicle stopped immediately if there were any obstacles in its path. Then again, the operator had to take action, as the representative of Wiener Linien highlighted: "He is the one that then simply decides: Can one go on or can one not go on?"[20] The operator also told me about another type of interaction that I recognized: "If there is, for example, a construction site, then a section of the route needs to be driven manually. Then one needs to change to the

18. „Es ist halt nicht wahnsinnig, es ist halt nicht die wahnsinnige Leistung, die jeder Bus erbringt, also der fahrt quasi auf unsichtbaren Schienen, so. Und bleibt bei der Kreuzung stehen und sobald irgendwas in sein Sichtfeld eindringt, bleibt er auch stehen. Also der bleibt glaub ich mehr stehen."
19. „Das Fahrzeug kann auch nicht ausweichen. Also er fährt seine fix programmierte Strecke, ob und wenn da ein Hindernis auf der Strecke ist oder in seinem Gefahrenbereich, was halt programmiert ist, was sein Gefahrenbereich ist, dann bleibt er einfach stehen."
20. „Weil eben der derjenige ist, ja dann wenn der, wenn das Fahrzeug stoppt aufgrund eines Hindernisses, dann ganz einfach entscheidet: Kann man weiterfahren oder nicht weiterfahren?"

joystick and drive this section manually."[21]

In light of these findings, I want to return to the goals of the operation: The test operation provided a solution to the problem of automating a bus line, but this goal was only attainable through manual intervention by the human operators. The automation was largely limited to following the invisible track defined by the buses' programming. The only truly interactive and spontaneous action performed by the machine was braking. Therefore, stopping has to be understood as a central function of these AVs, which at first might seem antithetical to the idea of automating driving. But driving is as much about breaking as it is about steering and accelerating. The sociotechnical setup of the test operation aimed to automating all of these aspects as much as possible. These insights help to differentiate the job of the operator from a driver: There was no need for constant human input, because in principle the vehicle could accelerate, brake, and steer by itself. The operator primarily monitored the machine doing the work and only engaged once the system reached its operational limits. Other configurations between automation and manual control would are possible: For example, the bus could simply follow its pre-programmed route regardless of obstacles and other road users, and the operator could be tasked with constantly controlling the brake. The sociotechnical assemblage of the test operation went one significant step further: The shuttles reacted dynamically to the traffic situation, even if their reaction was limited to stopping.

According to technical terms, the implementation of the Autonom Shuttle resembled level three conditional driving automation on the scale by the SAE (2021). Specifically, the ADS of the buses performed the dynamic driving tasks (DDT), meaning that it controlled all the vehicles' movements through traffic. It was also capable of object and event detection and response (OEDR). But there were three major limitations: The automated driving functions were only available for a strictly defined ODD, which was equivalent to the programed route, the ADS was incapable of crossing intersections automatically, and the only response that the buses could perform was stopping. Once the limits of the ODD were reached, or the ADS initialized a stop, the operator as the fallback-ready user had to perform the dynamic driving task fallback (DDT fallback) and take over control. As the bus would always perform a full stop, there was no time pressure, nor was there the need to verify whether the fallback-ready user was indeed ready. Theoretically, the operator had all the time in the world to tell the bus to continue its programming or grab the gamepad for

21. „Wenn eine Baustelle beispielsweise ist, muss halt ein Teil dann manuell fahren, wenn, dann muss man dann halt umsteigen wieder auf den, auf den Joystick und uns dann quasi manuell diese Strecke abfahren."

manual control. This simplicity makes a conceptual differentiation of handover situations superfluous (McCall et al., 2019). Building on the critique by Stayton and Stilgoe (2020), the formalistic differentiation of automation levels is of little use. While the chain of automation employed for the test operation checked certain boxes, the technology of the Autonom Shuttle was still much more limited than the definition of level three automation suggests.

The test operation offered certain automation features, but claims made in PR material (NAVYA, 2020; Wiener Linien, 2021b) went one step further: The buses were presented as autonomous vehicles. I would expect a high degree of agency from an autonomous being, as autonomy presumes independence and free will. The claim of autonomy raises many questions: What does autonomy mean for the operation of the vehicles? What is expected from an autonomous bus? How does autonomy relate to automation? These questions have important consequences for the problematization the actor-network answers to, as well as for the chain of automation. The representative of Wiener Linien defined the autonomy of the vehicles in narrow terms: "Well, that it can drive the route thanks to its programming, and that it can stop if an obstacle comes from the outside. … [The autonomy is limited] to driving on the track, yes."[22]

My interview partners shared the belief that the autonomy of the buses was limited to following its programming. In addition, the vehicles were capable of stopping in front of obstacles by themselves. I want to focus on the formulation that obstacles would come from the outside: According to this inside-outside distinction, the programming of the buses, and consequently, the chain of automation reacted to conditions outside its internal logic. Therefore, the AVs not only executed known instructions but also reacted to the unknown by stopping in front of it. This reaction by the machine was predetermined, but the trigger was not. The vehicle somehow recognized whether something was an obstacle or not. This ability might have been more important for the proclaimed autonomy of the buses than the actual driving performance: While the automation of the route posed a considerable infrastructural challenge, as described in subchapter 6.2, it was entirely predetermined: It was about defining invisible rails for the bus to drive on, not about reacting to the ever-changing environment. In a similar vein, Latour's infamous door closer (Johnson, 1988) also executes the same task delegated to it regardless of the

22. „Na in dem Fall ist es ganz einfach, dass er die Strecke aufgrund seiner Programmierung so abfahren kann, und dass, wenn von außen ein Hindernis einkommt, dass er stoppt. … [Die Autonomie ist limitiert] auf das Fahren von der Strecke, auf der Strecke, ja."

circumstances: It closes the door, whether or not it crushes the nose of a passerby.

In the case of the auto.Bus project, the implementation of automated driving went one step further by introducing a condition: If there was an obstacle, the bus immediately stopped following its predetermined path and came to a halt. As already argued, this is the simplest approach to implementing OEDR and DDT fallback functions, but it is valid nevertheless. Similarly, a door closer only gets active once the door was opened. This condition is enacted through physical contact: "The groom is quite good in its anticipation that people will push the door open and give it the energy to reclose it" (Latour, 1992, p. 237). But the moment of physical contact would have been too late for safely operating in Seestadt. So how did the bus know that there is an obstacle? The operator raised an important point in relation to this question: "It [the bus] makes no difference, unlike a human, who reacts differently if there is a box lying on the street or a child falling down. It always brakes. If there is a pile of snow, it does an emergency braking."[23]

This statement highlights a key limitation of how the AV reacted to dynamic changes: The vehicle, unlike a human actor, did not distinguish between different kinds of obstacles, so its reaction was always the same. In this regard, the shuttle bus and the door closer are very much alike. Both perform the same action delegated to them without considering the context of the situation. From a human standpoint, both technologies seem to be characterized not so much by smartness, but by dumbness – if one resorts to such pejorative terms. Then again, these non-human actors perform reliably because of their ignorance. But there remains a paradox to be solved: If the bus could not identify the type of entity blocking its path, how did the system know that something or someone is an obstacle in the first place? In Seestadt, the bus was surrounded by all kinds of objects. Apparently, most of them were not being classified as roadblocks, otherwise the vehicle would not have moved at all. How the obstacle recognition worked remains an open question that will be answered while exploring the chain of automation further.

Before moving on, I again want to reflect on the problematization and goals of the actor-network: The aim of the test operation was to automate the driving functions of the shuttle buses as much as possible. The vehicles drove automatically on their predefined route, recognized obstacles, and stopped in front of them. The automation and proclaimed autonomy of the machines was limited to following the pre-programmed route and

23. „Der macht keinen Unterschied so wie ein Mensch, ob da jetzt eine Schachtel auf der Straße liegt wird er anders reagieren, ein Mensch, als wie wenn da ein Kind auf die Straße fällt. Bus macht keinen Unterschied. Der bremst überall gleich. Wenn das ein Schneehaufen ist macht er eine Notbremsung."

stopping. Therefore, the AVs depended on the human operators in a variety of situations, both planned and spontaneous: At certain points along the route, the vehicles were programmed to stop and only continued once the operator pressed a button. The same process took place after the buses stopped in front of an obstacle. Certain sections of the route were not automated at all and had to be driven manually.

How did the AVs achieve this level of automation? From an ANT perspective, the buses did not possess the power to act autonomously or drive automatically by themselves. Instead, these capabilities resulted from the interactions between all actors of the network. As Michael puts it: “One therefore does not study ‘power’ but ‘relations of power’” (2017, p. 22). The chain of automation structured these relationships in a way that made the routine of the operation possible.

As shown in the previous subchapters, this chain involved a large and diverse cast of human personnel and non-human technologies. Heterogeneous entities like GPS signals, road users, touch inputs, operators, and passengers coordinated their actions to achieve the automation of public transport. Rather than limiting social relations to human beings and presupposing hierarchical deepness, ANT approaches this situation as a network of heterogeneous actors defined by radical flatness: “None of these ingredients can be placed in a hierarchy, or be distinguished according to its nature” (Callon, 1986b, p. 23). From this perspective, there is no a priori distinction between the bus, the components of the networked infrastructure, the passengers, or the operators. They all appear as isomorphic nodes of a network that should be studied symmetrically using a single repertoire of concepts (Callon & Latour, 1981; Callon, 1986a; Michael, 2017).

A main strength of ANT for analyzing the test operation is that it goes beyond dominant dichotomies, like the social and the technological, or the human and the non-human. It recognizes that in principle all kinds of actors possess agency. As Michael (2017) argues, agency can either result from the network as a form of distributive agency or get ascribed to an actor as a form of attributive agency. This egalitarian conception of agency fits my empirical observations: Every element of the test operation effectuated agency by doing or contributing something indispensable to the network. The bus regularly stopped without apparent reason, leaving the operator surprised and puzzled. In other cases, the operator took over control from the ADS after it was confused by a traffic situation. Both actors possessed different forms of agency. One might criticize such a perspective as naive anthropomorphism because the technical parts and the programming of the AV are not as human as the operators. Latour replies to such arguments as follows: “I do not hold this bias (this one at least) and see only actors – some human, some nonhuman, some skilled, some unskilled – that exchange their properties" (1992, p. 236). This awareness towards the agency and active role of non-humans was present throughout all the interviews, especially in relation to the technological artifact of the bus: He[24] – the bus – would drive, stop in front of other road users, or get confused by its environment.

When asked about the characteristics he would ascribe to the shuttle, the operator explained that he would watch over the vehicle like a teacher watching over a child: "Because one sits there and waits: What is he doing now? Haha, and then he is doing something. Ah, no, no! Haha."[25] The comparison between the AV and a human child expresses the idea that it had a will of its own and was able to learn. It also supposes a great knowledge gap between the ADS and the operator. This divide hints towards the irony of automation (Bainbridge, 1983) and the importance of human drivers for automated driving (Stayton & Stilgoe, 2020; Tennant & Stilgoe, 2021): State-of-the-art ego-only AVs are complex robots, but traffic on open roads poses challenges that surpass the capabilities of any automated system. Thus, the automation of driving under such open conditions results in so many issues and uncertainties that only a skilled human can compensate for the inflexibility of the robot. If you want to replace the driver with software, you need a human in the loop. Accordingly, the awareness towards the agency and will of the machine among the interviewees was contrasted by the already mentioned conviction that the AV's behavior was predetermined: The researcher from the AIT explained that "he acts very much by rules,"[26] and the operator presented the bus-child not only as unpredictable but also as obedient: "He does what you program him to do."[27]

In these statements, the autonomous shuttle buses are conceptualized as being limited to a strictly defined set of rules and programs while also showing signs of agency and autonomy. This paradoxical description can be explained by returning to the question of how the buses managed to drive automatically, and consequently, to the chain of automation. On multiple occasions, the interview partners pointed out that the artifact of the shuttle actually comprises many different technologies that handle certain subsets of the driving task. In addition, the AVs relied on preexisting resources for their operation,

24. The grammatical gender of the noun "bus" in German is male. Hence, my interview partners predominantly addressed the AV as a he. They might also have conceptualized the bus as a male subject, which would be in line with the anthropomorphization of the bus present across all interviews.
25. „Weil man sitzt eigentlich dort und wartet: Was macht er jetzt? Haha. Und dann macht er irgendwas. Ah, du du! Haha."
26. „Er handelt sehr stark nach Regeln."
27. „Der macht das, was man ihm programmiert."

most importantly the maps of the environment that were already discussed in subchapter 6.2. Rather than conceptualizing the limited form of autonomy and the self-driving functions as features of the AV, these capabilities should be understood in relation to the networked infrastructure of the test operation. According to ANT, the bus was not an isolated entity, but existed in relation to the actor-network:

> Accordingly, technical objects must be seen as a result of the shaping of many associated and heterogeneous elements. … Therefore, we cannot describe technical objects without describing the actor-worlds that shape them in all their diversity and scope. (Callon, 1986b, p. 23)

At the same time, one can zoom in on the vehicle to realize that was not only shaped by the overall actor-network, but that it also presented a network in itself:

> If we wish to construct a graphical representation of a network by using sequences of points and lines, we must view each point as a network which in turn is a series of points held in place by their own relationships. The networks lend each other their force. (Callon, 1986b, p. 31)

The chain of automation coordinated all involved actors and networks in a predictable and functional manner. Nevertheless, some translations failed, leading failures that seemed puzzling to human actors like me and the operator. The sudden braking of the bus in the middle of an empty crossing was such a case. The buses appeared to have a life on their own because they combined different agencies that did not always interact as expected. In this sense, these artifacts possessed a form of autonomy that went beyond their programming. But this limited autonomy did not conform to the notions of technological smartness or artificial intelligence prominent in the current automated driving discourse.

Up to this point it, I argued that the automation was achieved by actor-network and that both human- and non-human actors actively contributed to the operation. The project partners set up a chain of equivalences – I called it the chain of automation – which coordinated the actions of the involved actors. As a result, the buses drove semi-automatically along the route. To understand how this chaining of actors works, I need to analyze the translations that bound the actors to the network. Translation can be defined as “a definition of roles, a distribution of roles and the delineation of a scenario” (Callon, 1986b, p. 26). Only if the translations held, the chain of automation became stable, and the routine of the test operation worked as expected. I will continue with outlining the most important translations as described by the interview partners. By tracing these translations, I will be able to answer the remaining open question of how the buses know that something is an obstacle.

The most important ingredient for the recognition of objects were the 3D maps of Seestadt. In order to make the automation possible, the maps first had to be edited or "cleaned out," as the researcher from the AIT explained:

> Everything that is static, like edges of houses, sidewalks, and the like, all that stays and he uses that for orientation. And everything that is flexible, like cars that are parked there, people that are recorded, they are just, they are taken out.[28]

NAVYA employees then programed the complete route by drawing a line into the map that the buses followed. As insights from the Digibus project show (Rehrl & Zankl, 2018), fixed variables like speed and traffic regulations had to be coded as well. The interviewee from the KFV described the interaction between the buses and the programmed path as follows: "You can imagine it as if you have a blind person that moves along or feels his way along a string"[29] The characterization of the bus as blind expresses that the vehicle followed a set of commands without having an intrinsic sense of direction. But as the operator made clear, the AV was not without orientation. As described in subchapter 6.2, the ADS obtained the accurate position of the bus by referencing the GPS signal to the antenna on top of the metro station. The system also used point-cloud mapping as an additional localization technique (Levinson, Montemerlo, & Thrun, 2008; Yurtsever et al., 2020): The prerecorded, edited outlines of the environment were compared to the live feed of the LiDAR sensors. With this information in mind, it is now possible to trace the translations that resolved two major problematizations of the actor-network: On the one hand, how the AVs decided on the correct path through Seestadt, and on the other hand, how they recognized their surroundings and oriented themselves. First, NAVYA engineers translated the environment of Seestadt into a 3D map. Then, they translated the actual route of the test operation into a path through the map and a series of driving instructions. The buses translated these commands into movement by synchronizing their location in the real world to their location along the path in the digital representation of Seestadt.

Throughout the process of translation, a series of transformation is taking place, as Callon explains: "Through the designation of the successive spokesmen and the settlement of a series of equivalencies, all these actors are first displaced and then reassembled at a certain place at a particular time" (1986a, p. 217). The map spoke for and equated to the

28. „Also da wird dann das, was wirklich statisch ist, Häuserkanten, Gehsteigkanten und dergleichen, das bleibt drinnen, an dem orientiert er sich. Und alles, was flexibel ist, also Autos, die da geparkt sind, Leute, die damit erfasst werden, die werden eben, die werden rausgenommen."
29. „Das kann man sich so vorstellen, wie wenn man einen Blinden hat und der zieht sich entlang sozusagen, tastest sich entlang einer Leine halt eben diesen Weg ab."

built environment of the quarter. In a similar vein, the GPS location of the vehicle equated to its physical location, and the programmed route equated to the physical movements of the buses. Taken together, these series of equivalences made up a significant part of the chain of automation. Furthermore, the displacement of actors by the chain of automation correlated with the re-assembly of Seestadt into the networked infrastructure of the test operation. The operation of the AVs thus constantly reproduced the urban assemblage of the test operation. Seestadt's multiple urban realities cannot be separated from the networks and practices shaping them: "Space, scale and time are rather multiply enacted and assembled at concrete local sites, where concrete actors shape time-space dynamics in various ways, producing thereby different geographies of associations" (Farías, 2012, p. 6). One such geography of associations was the test operation.

A third problem remains: How did the vehicles recognize other entities crossing their path? With the already established set of translations, they could have only moved safely in an otherworldly version of Seestadt, containing only of immovable objects. Contrary to the statement that the bus was blind, the representative from Wiener Linien told me just how sharp the eyes of this machine were: "There are sensors directly on the bus that scan the immediate surroundings. And as soon as, for example, a leaf enters this environment, it is perceived as a threat."[30] The LiDAR sensors mounted to the vehicle constantly monitored the environment, thus reenacting the initial mapping of the environment by NAVYA. The algorithms of the ADS then used this data to compare the current state of the environment with the fixed dataset. The aim of this comparison was not only localization but also the recognition of objects that did not exist in the original data. The results were also communicated to the operator through the terminal inside the bus, as he described: "And then the screen also shows what is in the danger zone, or rather you can see if something is in the way. Then it points there."[31] Once an obstacle entered the predetermined safety zone, the bus initialized an emergency braking. Thus, the existence of an entity that was not recorded in the preexistent map equated to an obstacle, and the proximity of that obstacle equated to an emergency stop. In summary: The recognition of obstacles works by translating the environment into data and by comparing this data to a preexistent dataset. This function of the chain of automation was dynamic, as it translated reality in real time, but also inflexible, as every discrepancy equated to the same result: hitting the

30. „Und zusätzlich gibt's dann eben Sensoren direkt am Bus, die eben das, das unmittelbare Umfeld abtasten. Und sobald eben in dieses Umfeld hinein, ich sage jetzt ein Beispiel, ein Blatt kommt, wird das sozusagen als Gefahr wahrgenommen.“
31. „Und dann zeigt der Bildschirm auch an, was im Gefahrenbereich ist und, beziehungsweise, sieht, man sieht ja jetzt auch, wenn etwas stört oder was, dann zeigt er dorthin.“

brakes.

Whether there was an obstacle in the way or not, sooner than later, the chain of automation resulted in a stop: Either the AV required confirmation from the operator to continue, or the operator had to take over control, or the operator initialized a stop manually, or the vehicle reached one of the stops. In any of those cases, the operator had to take action. He either had to restart the automation, which signified that the road was clear, or he had to take over control, which equated to a situation that could not be handled through predetermined actions by the non-human actors of the network. Thus, the operator formed a central link in the chain of automation, as he presented an exception to the rule of automation while making the automation feasible in the first place.

Combining all outlined translations gives a complete overview of the chain of automation, which was at the core of the test operation. As the empirical data showed, the automated driving of the buses depended on a complex actor-world and the interaction between many heterogeneous actors. From an ANT perspective, it is not the bus which was autonomous or automated. Rather, the actor-network of the test operation structured the associations between the involved actors in a way that resulted in the automation of public transport. The chain of automation gave agency to non-human actor, which could be interpreted as a form of autonomy. But the resulting agency or autonomy was relational and not a feature of the technology. The test operation answered to the problematization of how one can automate the transportation of passengers and the driving maneuvers of the shuttle buses. This networked infrastructure laid out a series of OPPs that forced actors into detour and associated them to the network: The vehicles needed a route to follow and techniques of orienting themselves in the real world. But they also needed to know about spontaneous changes in the environment, like obstacles entering their path. As the AVs only had a limited understanding of what was happening around them and got overwhelmed easily, they required support by the non-human actors of the network and the helping hands of the operators.

Laying out this geography of obligatory passage points, enrolling the other actors, assigning them to their respective roles, and coordinating their collective actions was a complex and lengthy process. It took the project partners around five years to realize the auto.Bus Seestadt research project and the infrastructure of the test operation. In the next two chapters, I will explore how the chain of automation was stabilized and how the project developed over time. In order to do so, I will turn my attention to the agents of network building – the partners of the project consortium. An exclusive presentation of the bus acts as the entry point for this analytical step. The live demonstration also illustrated some of the translations and limitations of the chain of automation in more detail.

6.5 Enjoying a Live-Demonstration

Figure XII: One of the buses blinking through the grate of the garage door.

Here it is, the garage of the autonomous buses my interviewees told me about. It is located near the end of the bridge of the metro station. Underneath is a locked parking garage to which I would normally pay no attention to. But I know better and peek through the grate. Aside from a few scattered cars, there is another garage with closed roll-up doors inside. One of the buses is visible through the mesh of the gate. So this is the cozy home the shuttles return to after a long morning of driving. A man already recognized me and lets me in. *Are you the interviewer? Yes, I am.* He is one of the operators and agreed to answer my questions about the operation. Getting a behind-the-scenes tour is a welcomed change after all the interviews held over Zoom. I hope for a lot of detail on the routine of the operation and the infrastructure. As it turns out, I won't be disappointed.

We enter the bus garage and look for a place to sit down. The interior looks like a spartan mixture of office and workshop: cement floor, tools, desks, workbenches, storage racks, chairs, paperwork, and a computer. We take a seat inside the bus, which seems fitting. But I realize that there is a problem: It is loud, very loud. Have the buses been always that noisy? The voice recording would sound abysmal. *Should he turn off the bus? Yes, that would be great.* In the end, we take three chairs – one for the voice recorder – and sit down next to the empty parking space reserved for the second bus, which is currently driving through Seestadt. *After the interview, you can look at the bus as much as you want.* Amazing! There never was the opportunity to photograph and videotape to my heart's content. But let's start with the interview first …

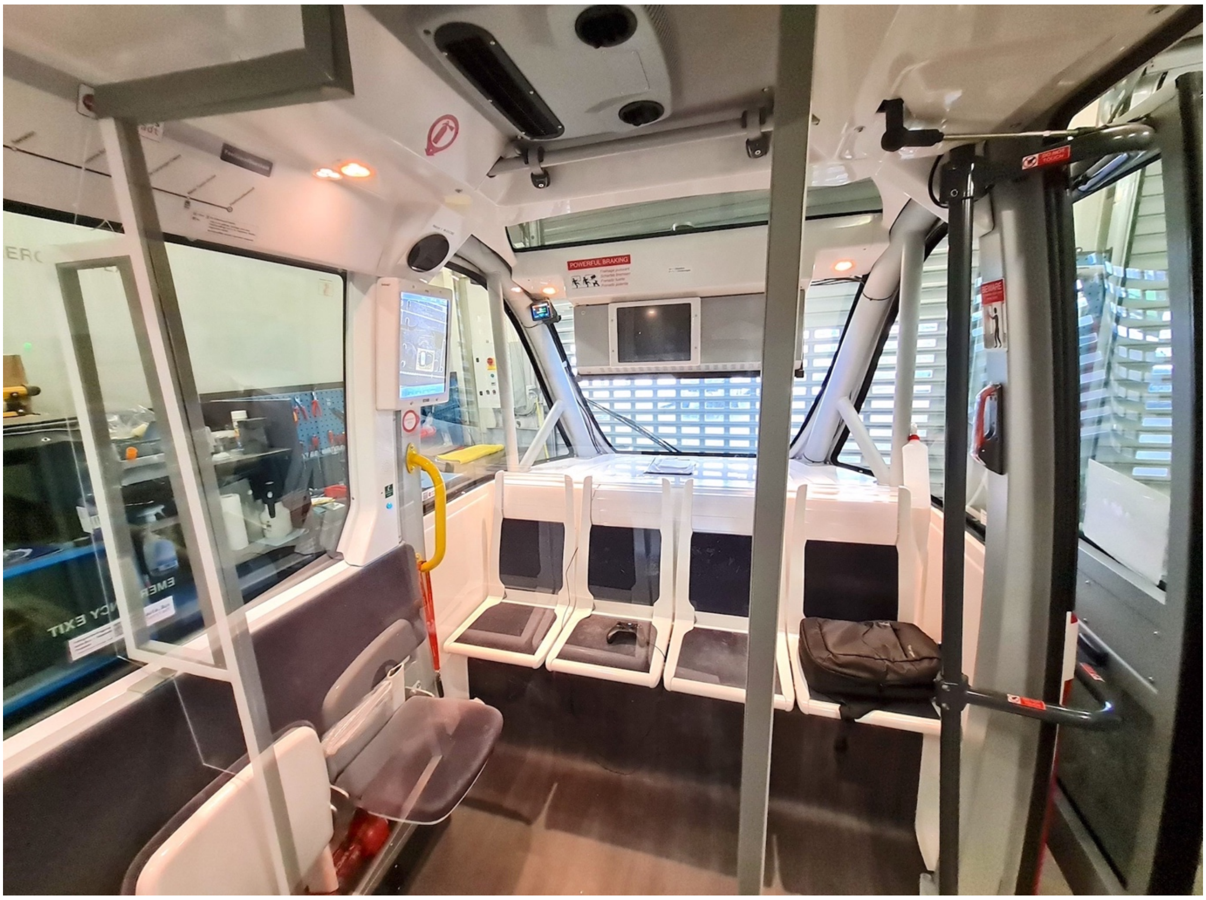

Figure XIII: The interior of the bus. Note the XBOX gamepad lying on the seats, which was used for manual driving, and the terminal screen.

The voice recording is still bad. There is loud humming in different pitches, like if we were sitting in some kind of machine room. Actually, this is a fitting description of this scene. Right after the start of our conversation, we are interrupted by another operator returning to the garage with the second bus for his break. He probably recognizes me, the strange student, but we only exchange a brief look before continuing with the interview. As we speak, I remain conscious of my surroundings. The existence of the garage, the maintenance taking place here, the office supplies, the tools, the operator returning for his break – this is the backstage of the test operation. It hints at a routine performed by professionals. The auto.Bus project might have been about research, but it also was about very practical considerations. Even though the operator and I are talking inside a pretty mundane garage, this is all very exciting to me.

As promised, the operator lets me take a detailed look at the bus after finishing the interview. I try to locate all the sensors he just told me about: eight LiDAR devices, two cameras, and several other integrated sensors for measuring driving-related statuses like speed and acceleration. These sensing technologies are part of the standard equipment of the Autonom Shuttle. But this particular vehicle was augmented with additional technology after the fact: Behind the front window, there are three cameras implemented by researchers from the AIT for an experiment. The idea was to use the image data to automatically differentiate between different kinds of obstacles, which could have drastically improved the ADS. However, this experiment was never translated into daily practice. There is another piece of custom equipment inside the bus, on the top left corner of the windshield: a small status display connected to the I2V communication system at the intersection between lse-Arlt-Straße and Maria-Tusch-Straße. In principle, this system would display information on approaching vehicles and allow the ADS to turn automatically, but in practice, the screen only shows the current distance to the crossroads and the speed of the vehicle. There is not much else to see in the garage, except for the power cables that are used to charge the vehicles overnight.

Figure XIV: Overview of the interfaces available on the terminal and the sensors added to the vehicle by the project partners. From left to right: (1) visual representation of the point cloud matching technique. (2) Interface showing odometry information of the vehicle. The small screen on the windshield was connected to the awareAI I2V communication system. (3) Status information on the different software components, the event log, and the button for performing a hard reset of the ADS. (4) Three additional cameras fixed on the windshield. These were used to test experimental object recognition functions.

During the interview, the operator mentioned the GPS antenna on top of the metro station and asked whether we should go check it out. *Of course I want to.* How would we get there? We decide on the most sensible option: We would go for a spin in the shuttle bus. This would be an exclusive demonstration! After booting up the vehicle, the operator needs same time to pack. In the meantime, I inspect the inside of the vehicle. The terminal screen now shows a bird's eye view of the bus on a noisy map of the surroundings. Yellow lines and dots surround the vehicle and conglomerate along the outlines of the environment. The ADS is already sensing and palpating the world in the search of obstacles. While watching these visuals, I feel like I am looking into the head of this machine. What do these colors and shapes tell me? My musings are interrupted by the return of the operator. *Let's go*. By using the gaming controller, he maneuvers the bus out of the parking garage. The AV will drive the rest of the way to the metro station automatically, or at least as automatic as it gets with this technology. I never thought about the vehicle and the operator sharing their commute in the morning. Somehow, this is a romantic thought.

Figure XV: This interface shows the blue paths the bus followed, as well as the visual representation of the point cloud matching technique.

Once the vehicle is in position and the operator presses the much-discussed button, the automation of driving works as expected. But because this is an extraordinary trip and the interview situation still resonates with us, there is more time and space to reflect on what is happening. As we drive, the operator directs my attention to the terminal and to what is happening on screen. The aforementioned interface displaying the machine's vision is being updated in real time. The bus icon on the map and the movements of the bus are synchronized, with yellow dots sweeping over the abstract outlines of the environment. He points towards two blue lines delimiting a corridor. These lines are what another respondent called “the invisible strings” the bus keeps following. I observe how the eyes of the operator constantly switch between the bird eye’s view on the screen and the real world outside the windows. Two perspectives collide: We observe how the bus automatically moves down the road. Parallel to this movement, the screen shows the icon representing the bus following the blue path across the map. In my head, I recap how the automation unfolds: The LiDAR sensors constantly send pulses of laser beams into all directions. These signals are reflected by the objects in the environment and, after being processed by the on-board computer, form the yellow dots on the screen. This feed from the LiDAR sensors is compared to the original dataset, which enables both the precise localization of the vehicle and the recognition of obstacles in real time. If the sensors recognize an entity that does not exist on the map, then this object is being interpreted as an obstacle. Once it gets too close, the bus initiates an emergency braking. Today, there are no such interruptions, and the chain of automation works flawlessly.

This was not always the case. In the interview, the operator told me about the long process of achieving the relatively stable state of the operation. To him, the project was about a series of small improvements rather than sudden breakthroughs. Many of the challenges that the project partners encountered are of practical nature and can be related to what I observed during our ride.

As we slowly drive towards the metro station, the operator flips through different user interfaces on the terminal. Every page is tailored to a different use case, among them the previously discussed interface displaying the machine’s vision or the frequently used go-on button placed under a map of the route. There is also a page for diagnostic purposes that includes a status monitor of all the subsystems of the ADS, like the different sensors, as well as an event log that documents problems that the driving software encounters. This interface includes a button for performing a hard reset of the system. Just like with personal computers and printers, turning the AVs on and off is crucial for overcoming all kinds of issues. The operator told me about a particularly challenging issue that was hard to fix: Between ten and eleven in the morning, the GPS connection repeatedly dropped, probably because of an unfortunate satellite constellation. This led to the buses not moving at all, because the synchronization of their physical location to their position on the map failed. The operators waited, performed a hard reset, and tried again.

Or they phoned NAVYA hoping for better advice. There was only so much that the personnel of Wiener Linien could fix on their own, e.g., by making a hard reset. NAVYA did most of the heavy lifting, as the buses are their product. There even is a dedicated button inside the bus that establishes a direct connection with an employee in France. *Did you ever press that button? Yes, once by accident.* The person on the other end apparently said something like "What can I do for you?" The bad satellite reception was not fixed this way, but eventually the buses were programmed to rely more strongly on the point cloud maps generated by the LiDAR sensors whenever tracking via Multi-GNSS RTK failed. Such systemic changes were out of reach for the operators, but in other cases, a hard reset and patience did the trick.

Another practical concern of the operation was the relationship between automatic driving, manual inputs, and the programming of the route. During our ride to the metro station, there were only two situations in which the operator had to reach for the joystick, thus fully taking over control: when we left the garage and when we parked the vehicle underneath the metro station. The AV drove the rest of the route automatically, except that the operator pressed the on-screen button from time to time, telling the bus to go on or stop. This interface element works like the play/pause/resume button on a media player. It stops or continues the script of the bus. At a particular intersection, the vehicle had to turn left from Sonnenallee into Seestadtstraße. Shortly before reaching the crossroads, the operator initialized a stop by pressing the button. He then looked to left and right and pressed the button again to resume the automatic driving. The vehicle slowly turned left.

Why was this conditional form of automation possible at more complex points along the route, like at this intersection, while simpler situations required the operator to take over control? The section right after the metro station comes to mind, which was driven manually even though the bus could have simply gone straight. The operator explained that the driving mode depends on whether there is a programmed path for the vehicle to follow. The way from the garage to the metro station is fully scripted, but other parts of the route are not. The section right after the metro station had to be driven manually because it was missing in the program, not because it was too complex.

At another point along the route, it turns out that the programming of the bus is more throughout than I thought. As we approach the rotary before the metro station, I expect the operator to reach for the controller and manually perform the sharp turn. But instead, the vehicle slowly comes to a stand and waits for further instructions. After the operator checked that the road was clear and pressed the button, the bus slowly turns into the bend. Shortly before we leave the rotary, the operator stands up from his seat and parks the vehicle using the gaming controller. He only had to steer manually because he wanted the bus completely off the road.

Figure XVI: View from the roof of the metro station. The device in the foreground is the GPS reference antenna.

It is now time for the last activity on our list: taking a look at the GPS antenna on top of the station. I follow the operator through passageways only Wiener Linien employees may use until we reach the roof. It is rough up here, with the wind blowing and a lot of moisture from the drizzle. The operator already warned me that the GPS antenna is pretty unimpressive, and I have to agree: It is a small box with another device connected to it, nothing fancy at all. By contrast, the view from up here is amazing. I enjoy the exclusive panorama of the lake and the skyline of Seestadt. It feels like a good way of concluding a day of fieldwork. As I take the metro back to my apartment, I reflect on all the small anecdotes about the project partners dealing with the issues of the automation technology. If one ignores that the operators could simply drive the shuttles much more efficiently, then Vienna's first autonomous bus line works surprisingly well.

6.6 Implementation as Translation

The previous analysis of test operation focused on its infrastructural characteristics and the actors that were associated with the actor-network, as well as on the interactions between the actors that made up the chain of automation. I also learned about a series of issues, challenges, and interdependences that had to be addressed by the implementation process. My account was mostly limited to the late stage of the auto.Bus Seestadt research project, at which point the actor-network was already stabilized.

During my last exclusive ride with the bus, the operator and I reflected on how various challenges were overcome throughout the project runtime and how the corresponding solutions and workarounds shaped the final state of the operation. In conclusion to this chapter, I want to reconstruct the evolution of the project and the steps of the implementation process throughout the project runtime. I interpret the integration of the test operation into Seestadt as the work of building a network. The auto.Bus Seestadt project dated back much earlier than my fieldwork. The project partners started their research in 2017, but a lot of preparatory work took place even earlier. I will analyze their efforts across four phases: first, the formation of the research project and the project consortium, second, the initial testing of the vehicles and their public presentation on multiple occasions, third, the implementation of the test operation into the district, and last, the start of the public test operation.

The first phase of the auto.Bus research project began in 2016 and encompassed the project partners joining the consortium, the writing and submission of the funding application, as well as a separate application for testing the autonomous vehicles on public roads. In the previous subchapters, the coalition of the project partners appeared as given fact, but it was during the first phase that the different parties were interested in the research and got ascribed their respective roles. The formation of the project consortium is connected to the implementation of the test operation because the latter was the outcome of the ongoing cooperation between the involved organizations. So in order to analyze the process of implementation, I need to broaden my perspective and study the consortium and the auto.Bus research project as a whole.

As Latour (1996) makes clear, an actor-network is neither a preexistent abstraction nor a technical system, but a consists of the sociomaterial connections between heterogeneous actors and the translations binding them to their designated place in the network. Only by paying attention to the involved actors, one can learn about their associations: “It is by engaging with the empirical specificity of the encounter between actors that we come to an understanding of its character – the elements that comprise it, and the outcome that follows” (Michael, 2017, p. 24). What is an actor in the first place? Callon and Latour provide a graphic definition: “Any element which bends space around itself, makes other elements dependent upon itself and translates their will into a language of its own” (1981, p. 286). An actor would either creatively define “the stakes and rules of the game,” or it would allow “another, more powerful than itself, to lay them down” (1981, p. 286).

Who were the actors that defined the rules of the auto.Bus Seestadt project and started interesting others into their game? According to interview data, personnel from the AIT and Wiener Linien initialized the research project. But they did not do so in limbo, but in a specific spatiotemporal context. As the researcher from the AIT explained, in 2016 there was a unique window of opportunity for doing research into automation:

> A few years ago, this was simply pushed a lot from the funding side, from the ministry. Funding schemes were announced and auto.Bus Seestadt is a funding application that arose in this context, for a special call on the topic of automation. And then the current partners of the project got together in a consortium to submit an application.[32]

The mentioned funding programs acting as impetus for the project were the Mobility of the Future research and development program (Federal Ministry for Transport, Innovation and Technology, 2012) and the Action Plan Automated Driving (Federal Ministry of Transport, Innovation and Technology, 2016). A major aim of these programs was to incentivize the testing of autonomous vehicles in Austria, which was made possible by new legislation: For the first time, the Automated Driving Regulation (AutomatFahrV) (Legal Information System of the Republic of Austria, 2016) enabled the testing of automated driving solutions in public under certain conditions and for several predefined use cases, among them autonomous minibuses.

32. „Aber es war halt vor ein paar Jahren auch sehr, sehr gepusht, von der Förderseite her, vom Ministerium her. Es wurden Förderprogramme ausgeschrieben und auto.Bus Seestadt ist eben ein ein Förderantrag, der in diesem Zusammenhang entstanden ist, auf eine, eine spezielle Ausschreibung zum Thema Automatisierung. Und da haben sich dann die jetzigen Partner des Projekts zusammengetan in ein Konsortium, um einen Antrag einzureichen.“

These policies and funding opportunities defined a framework that the AIT and Wiener Linien used for building the auto.Bus research project. A shared motivation among all partners for joining the project was to take advantage of the recent interest in automated driving and be among the first to test autonomous minibuses in Austria. Ba doing so, they would gain experience and expertise in working with AVs and automation in general. The representative of Wiener Linien explained: "So our goal was quite simply, or the starting point of the whole project was that we would put these autonomous vehicles through their paces."[33]

In order to realize the project, two major organizational challenges had to be overcome: On the one hand, the funding application had to be submitted, and on the other hand, the partners had to register the testing of AVs at the ministry. Wiener Linien acted as project leadership because of the company's experience in operating public transport services. The AIT took over the scientific leadership and was responsible for the submission of the test application. In the context of the AutomatFahrV, the Ministry for Transport, Innovation and Technology established a multi-step process for registering and implementing such tests, which positioned the consultative agency AustriaTech GmbH as an important intermediary (AustriaTech, 2021; Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, 2021). Indeed, my interviewees told me about the extensive coordination between the project consortium, AustriaTech, and the ministry throughout the project runtime. Rather than having been limited to a single interaction, the supervision of the project by the authorities was an ongoing effort and formed a crucial part of the implementation process.

To meet all the formal requirements and to realize their vision, the AIT and Wiener Linien requested additional partners to join the project consortium and contribute their expertise. The respondent from Wiener Linien explained:

> And together with them we asked ourselves: Well, who else do we need on board? And as you said earlier, you need a completely interdisciplinary team, because so many aspects have to be addressed in order to successfully implement the whole thing.[34]

The most prominent considerations for the enrolment of additional partners were the issues

33. „Also unser Ziel war es ganz einfach, oder der Ausgangspunkt von dem ganzen Projekt, dass, dass wir diese autonomen Fahrzeuge jetzt mal auf Herz und Nieren testen."
34. „Und gemeinsam mit ihnen hat man sich dann auch so überlegt: Na, wen brauchma denn dann jetzt noch alles im Boot. Und wie sie vorhin schon gesagt haben, da braucht's einfach ein ganz interdisziplinäres Team, weil einfach so viele Aspekte hier angesprochen werden müssen, um das Ganze erfolgreich einzuführen."

of security, safety, and liability in relation to the public testing of the autonomous buses. The representative of the AIT gave an overview of the challenges that they faced:

> And the process now for us as a research institute to register such a test: You have to submit an application in which you first describe the test, so what is being tested. Then you also have to specify the exact route. You have to clarify everything. Is the technology mature enough? Has it been tested sufficiently to be allowed on the road? Is there insurance, so how is the whole thing insured? How is guaranteed that the bus behaves safely? … All these things have to be described. Also, the district must be informed that a test will be carried out. And then you get a test certificate, which you then have to renew if anything changes.[35]

Some of these requirements were connected to the automation technology and the vehicle itself, so finding a suitable product was a major concern. The French manufacturer NAVYA provided its minibus model Autonom Shuttle, which met the required 1000 kilometers of successful test driving, as demanded by the AutomatFahrV. In addition, the company joined the project consortium, which the representative from Wiener Linien described as both a bonus and a standout feature of the auto.Bus project. It allowed for more in-depth cooperation, even though it might not have been mandatory for the project to succeed.

There were still open questions regarding the legal basis for testing of AVs and its translation into practice. These considerations revolved not only about the AutomatFahrV, but also about the Code of Practice (Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, 2020). This is a collection of legally non-binding suggestions for implementing test operations with the aim of minimizing liability and safety risks. This is where the KFV came in: Based on its legal expertise in road safety, the association helped the project consortium apply the Code of Practice to the test in Seestadt. The representative I spoke to outlined several challenges they encountered:

> But that is also a very big focus, to see how does it [the implementation of the test operation] even work and what legal issues arise from it? The ones simply not yet regulated in the ordinance, but which have to be considered. So there also is the Code of Practice, where you have to explain how you train the operators. What safety concepts do you have that go beyond what is required? … And then during

35. „Und der Prozess jetzt für uns als Forschungsinstitut, um so einen Test anzumelden: Da muss man einen Antrag stellen, wo man zunächst mal den Test beschreibt, was da getestet wird. Dann muss auch die Strecke genau angeben. Man muss alle, alles rundherum klären. Also ist, ist die Technologie ausgereift genug? Ist die schon genug getestet worden, dass man sie auf die Straße lassen darf? Besteht eine Versicherung, also wie ist, wie ist das ganze versichert? Wie wird sichergestellt, dass dass der Bus sich auch sicher verhält? … Alle diese Dinge müssen beschrieben werden. Es muss vom Bezirk auch, der Bezirk muss informiert werden, dass hier ein Test festgestellt, durchgeführt wird. Und dann bekommt man eine Testbescheinigung, die man dann, wenn sich irgendwas ändert aber auch erneuern muss.“

> the implementation, there are still open questions: Well, what does that actually mean in legal terms? What information do the operators need for this? How does this affect the operators?[36]

This statement again highlights the importance of the operators for the implementation of the test operation. Their presence was not only a practical consideration but also a legal and regulatory requirement.

The participation of TÜV Austria in the project consortium is connected to the safety and security of the AVs and their homologation for road use. The operator told me that the partners wanted to certify the vehicles, just like a regular bus. In this case, the AVs would have been eligible for a valid license plate. However, the Autonom Shuttle lacks some of the necessary security specifications. Therefore, the ministry issued a special permit allowing the buses to operate in Seestadt, but only on the specific route of the test operation. The last member of the project consortium was Siemens. A major outcome of this company's engagement was the already discussed camera system at one intersection, as well as the IoT devices integrated into one stop. Thus, Siemens was primarily responsible for the embedding of the test operation into the smart urban infrastructure of Seestadt.

When examining the initial phase of the auto.Bus Seestadt project through ANT, it can be summarized as follows: Actors from Wiener Linien and the AIT seized the moment and started working on the vision of the Ministry for Transport, Innovation and Technology to establish Austria as a test site for automated transport. The auto.Bus Seestadt research project would provide the framework for implementing the test operation of two automated minibuses at Seestadt. With the help of this experimental setup, it would be possible to try out the vehicles under real-world conditions. In order to get the necessary expertise and fulfill formal requirements, the project leaders interested the other partners in joining the consortium.

The way the project partners constructed the research project is similar to how Callon describes the approach of other technoscientists: "They determined a set of actors and

36. „Aber das ist halt auch ein ganz großer Schwerpunkt zu schauen wie ist das überhaupt und was für rechtliche Fragestellungen ergeben sich daraus? Auf die man, also die einfach noch nicht in der Verordnung geregelt sind, die aber bedacht werden müssen. Also es gibt ja auch den Code of Practice, wo man darlegen muss, eben wie schult man den, die, die Operatoren? Was hat man für Sicherheitskonzepte die einfach über das Gefragte hinausgehen? … Und dann in der Umsetzung gibt es aber trotzdem eben noch die Fragestellungen: Ja, was bedeutet das rechtlich eigentlich auch? Was für Informationen brauchen die Operatoren dazu, wie wirkt sich das auf die Operatoren aus?"

defined their identities in such a way as to establish themselves an obligatory passage point in the network of relationships they were building" (1986a, p. 204). As stated previously, the creation of an actor-network is intrinsically linked to the process of translation. Through the means of translation, Wiener Linien and the AIT transformed the interests of the other project partners so that their participation appeared as the logical conclusion. The collective of the project consortium would speak on behalf of all involved partners. Taking part in the research project and the test operation appeared as a way of answering to their individual interests. When asked about the reasons for testing the vehicles over an extended period, the representative of Wiener Linien made the following argument:

> Because it was simply important for us to cover many kilometers in autonomous driving, simply in order to gain as much experience as possible, and also to be able to adequately answer the different questions that came from the different partners.[37]

After forming the alliance of the project consortium, the partners proceeded with realizing their vision. They had to associate many more actors, enact new sets of translations, and pass several trials until the start of the test operation.

The second phase of the auto.Bus Seestadt project began once all the outlined organizational tasks were completed and the project leadership received both the confirmation of funding and the allowance to test the vehicles. Next, the project started testing the vehicles and prepared their implementation into Seestadt. This phase was about getting to know the buses and the related technology, about gaining publicity and interesting users, and about the re-assembly of Seestadt for the test operation. These efforts presented a shift from the work of building the network of the project consortium to the construction of the networked infrastructure and the translation of the involved actors into the chain of automation. As both phenomena were already discussed in detail, I will focus primarily on the construction of the actor-network in Seestadt.

The first milestone of the second phase was the delivery of the two shuttle buses by NAVYA in the beginning of April 2018. Their new home in Vienna was not Seestadt, but the bus garage in Leopoldau, which is part of Vienna's 21st district, Floridsdorf. The test operation would not start until more than a year later. Why the delay? According to the operator, it would have been impossible to use the vehicles out of the box, even with extensive support

37. „Weil es uns ganz einfach wichtig war, viele Kilometer in diesen autonomen Fahren zum, zum, abzuwickeln, einfach um möglichst viel Erfahrung zu sammeln und auch eben um den unterschiedlich, um unsere unterschiedliche Fragestellungen, die eben von den unterschiedlichen Partnern auch kamen, auch ausreichend beantworten zu können."

from NAVYA:

> That doesn't work at all, doesn't work at all, that he [someone from NAVYA] just comes here, programs its route somehow, and imports it and then it [the bus] drives. That doesn't work. It simply has to [adapt], to the environment. It's all kinds of different things.[38]

Therefore, the project partners started testing the buses in a controlled environment before moving them to Seestadt. They used the experience from this initial test to construct the actual test operation. In addition, the allowance to deploy the vehicles on public roads is linked to extensive prior testing. To this purpose, a simple track in the form of a figure eight with a stop and a traffic light was constructed on the area of the garage in Leopoldau. The basic requirements and interactions of the automation technology were the same as outlined in the subchapters 5.1 to 5.4, meaning that NAYVA made a three-dimensional scan of the environment and programmed a path for the vehicles to follow.

Another key requirement for the future test operation was the schooling of the operators. This job description did not exist yet at Wiener Linien, so three professional bus drivers received additional training from NAVYA. These men are part of a special department focused on bus innovations and regularly test new products. The operator I talked to described what he had learned during training:

> First of all, the whole driving behavior, driving manually with the vehicle, how to operate the vehicle, technical background, also NAVYA history, these were the things that we learned. Presenting the vehicle. And, yes, also the autonomous driving and then also small things, how to solve technical problems. With the error memory, how to analyze that, how to really fix that, things like that. So that you can help yourself in a few cases.[39]

Most of the operators' skills that I observed during fieldwork date back to this initial training. It also presented yet another instance of the close interaction between NAVYA and the other project partners. There certainly was a strong dependence on NAVYA's products, services, and expertise throughout the whole project. I suspect that this was an

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38. „Das ist, er kann, das funktioniert überhaupt nicht, [das kann] überhaupt nicht funktionieren, dass er [ein Mitarbeiter von NAVYA] einfach kommt, der programmiert seine Strecke irgendwie und spielt das ein und der [der Bus] fährt. Das funktioniert nicht. Der muss einfach an die Umgebung [angepasst werden], das sind verschiedenste Sachen."

39. „Es wurde das, erstens einmal das ganze Fahrverhalten, manuell Fahren mit dem Fahrzeug, wie man das Fahrzeug bedient, technischen Hintergrund, auch NAVYA Geschichte, solche Sachen haben wir gelernt. Das Fahrzeug präsentieren. Und ja, und auch das autonome Fahren und dann auch so Kleinigkeiten, wie man technische Probleme lösen kann. Mit dem Fehlerspeicher, wie man das analysieren kann, wie man das wirklich beheben kann, solche Sachen. Dass man sich [bei] ein paar Sachen selbst helfen kann."

unusual situation for Wiener Linien, as the company has its own maintenance and training infrastructure. To mitigate this interdependence, my interview partner later became a certified instructor and trained an additional operator himself.

How did the shuttle buses perform once these preparations had been taken care of? As it turned out, the expectations of the project partners were only partially met, especially regarding efficiency. While it was clear from the start that the vehicles would only transport very few passengers at low speed, the initial plan was to drive at up to 40 km/h while also allowing for non-seated passengers. However, this would have been far too unsafe: As I have already described, the automatic recognition of obstacles resulted in frequent full braking, which at higher speeds would have endangered passengers without the use of seatbelts. Therefore, NAYVA and Wiener Linien struck a balance: All passengers had to be seated and the maximum speed was reduced to around 20 km/h, but at least there were seatbelts. Later, the maximum speed was further reduced to 16 km/h.

The project partners made these compromises in relation to the problematization discussed in subchapter 6.4: Which adaptions the automation technology were necessary for the safe and semi-regular transport of passengers in Seestadt? It was during the second phase of the project that the consortium tried to interest additional actors as preparation for the future operation: “Interessement is the group of actions by which an entity … attempts to impose and stabilize the identity of the other actors it defines through its problematization. Different devices are used to implement these actions” (Callon, 1986a, pp. 207-208). The closed test of the vehicles, the training of the operators, and the various tradeoffs between safety and efficiency present such interessement devices. The prospect of a public test acted as a “geography of necessary points of passage” (Callon, 1986b, p. 27) supporting the interessement of actors.

Parallel to technical preparations, the partners started interesting the public in their endeavor. The aim was to position their research as an innovative flagship project directed towards the automated future of transport in Vienna, Austria, and Europe. The aspirations of the partners also went beyond academia, as the researcher from the AIT made clear: “And it was very important in the application that it is not just a research project.”[40] Besides its role as legal and safety counselor, the KFV was responsible for the dissemination of results and public relations. The representative laid out the chosen approach as follows:

40. „Und ganz wichtig war in dem Antrag, dass es eben nicht nur ein Forschungsprojekt ist.“

> Because the whole project is socially relevant, the testing of automated systems, but also because Wiener Linien participates, the goal was that they do or need to do a lot of public relations work. Also, that it should be accessible to a broad public, not only to the scientific community. And we then added that it would also be important to define the people of Seestadt as a third group, so all the people who are somehow affected by this implementation are addressed.[41]

In order to reach the different audiences, the research project and the artifacts of the buses were presented at a variety of events before the start of the test operation. These activities included: an information booth at the Long Night of Research, a live demonstration in the Interactive Zone of the Transport Research Arena (TRA) 2018 conference, an information event for Seestadt inhabitants organized by the aspern.mobil LAB, a presentation of the buses at the Street festival Maria-Tusch-Straße and a test track at the Vienna Research Festival. These and similar events all took place in 2018, building up momentum for the start of the test operation in the following year.

An occasion I want to focus on is the information event on the 17th of May 2018 in the bike shop and café United in Cycling, located next to the metro station “Seestadt”. This event was organized by the aspern.mobil LAB. While the lab was not part of the project consortium, it still supported the project by establishing contact with the local population. As the involved researcher told me, the event was in part a reaction to discussions among inhabitants of Seestadt on social media:

> It already became imaginable: Okay, such an autonomous shuttle really is coming to Seestadt. But it was still far away and there was very little information online. Almost nothing, actually. … And then, we already noticed that somehow among the residents, if you looked at it superficially, that fear was rising and that in comments that mentioned the bus there were many reservations, something like: Ah, I will be run over with my stroller because the bus overlooks it and does not recognize the stroller, or I don’t know. You could see that the connection to the technology was still very much missing.[42]

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41. „Und da war’s natürlich das Ziel, da es halt einfach gesellschaftliche Relevanz hat, das ganze Projekt, das Testen von automatisierten Systemen, aber auch die Wiener Linien dabei sind, dass die ja viel Öffentlichkeitsarbeit machen oder machen müssen. Auch, dass das auch einer breiten Öffentlichkeit zugänglich sein sollte, nicht nur der wissenschaftlichen Community. Und wir haben dann noch mit reinreklamiert, dass es da auch wichtig wäre als dritte Gruppe eben Personen in der Seestadt selber zu definieren, also alle Personen, die davon irgendwie betroffen sind, dass diese Implementierung stattfindet.“

42. „Es war no, es ist schon vorstellbar geworden: Okay, da kommt wirklich so ein autonomes Shuttle in die Seestadt. Aber es war no weit weg und es waren nur sehr wenige Informationen online. Also bis gar nichts eigentlich. Aber man hat schon gehört, irgendwo war dann schon so, ja, in einem halben Jahr, in einem Jahr kommt dieser Bus. Und da haben wir aber gemerkt, bemerkt, dass

Another concern was connected to the aspiration of the consortium that the operation of the buses would be more than a research project. Some inhabitants feared that the AVs would become a permanent and essential contribution to the local mobility infrastructure:

> It was simply seen critically, and many misunderstood it. They believed something like: This is now our new bus line, or what? Criticism like this came up: Now there's this stupid autonomous bus, which drives somewhere, somewhere around the corner, and takes forever. But the normal bus that drives through the city, Aspernstraße, Seestadt Aspern, is always crammed.[43]

So at first, a small subset of the local population resisted the enrolment into the network of the auto.Bus project, even though the partners told me that they predominantly received positive feedback from citizens throughout the project runtime. Fully getting the Seestadt community on board was a prime concern, as the project depended on the public's participation and cooperation. After all, the test operation not only tested the buses, but also the reactions and behavior of citizens. The presentation of the buses at various occasions and the encounter between a group of local inhabitants and the project partners relates to the discourse on acceptability in interesting ways. The paradoxical conceptualization of potential users as both rational decision makers and fearful, irrational individuals (Graf & Sonnberger, 2020) informed the chosen approach to some degree, but there are important variations: Instead of asking the public to accept automated driving technology as an abstract and vague concept (Stilgoe & Cohen, 2021), the project partners provided information on the concrete use case and product. In the beginning, this strategy apparently was not successful in convincing a subset of local inhabitants. Their concerns appeared as both irrational and rational, but the partners were convinced that more information would resolve the issue. By engaging in direct conversation, they took the local population seriously while ensuring the favorable reception of the project.

In order to interest the critics in joining the network, or at least prevent them from rebelling against it, the attendees of the project consortium managed expectations in a particular way: The operation would strictly be a test and not a regular mobility service. The AVs

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irgendwie schon im, in den, unter den Bewohnern einfach so ganz oberflächlich betrachtet so a bisse Ängste entstehen und so Kommentare, wenn der Bus vorkommt, so a bissi viele Vorbehalte einfach da waren und so a bissi: Ah da wird, da werd i mit meinem Kinderwagen nieder geführt, weil der Bus dann des übersieht und den Kinderwagen nicht erkennt oder I don't know. Also da war, da hat ma gemerkt, dass sehr viel a dieser Bezug zur Technologie noch gefehlt hat."

43. „Weil des einfach a kritisch gesehen worden is und viele des missverstanden haben, geglaubt haben, das ist jetzt unsere neue Buslinie oder wie? Also da geht's a drum, parallel zu verstehen, dass dann a so Kritik hochgekommen ist: Jetzt bringt's da diesen blöden autonomen Bus, der irgendwo fährt und ewig herumtingelt, irgendwo in, ums Eck. Aber weiß i ned, der Bus, der normale Bus, der durch die Stadt fährt, Aspernstraße, Seestadt Aspern, ist immer bummvoll."

would be nice to have, but nobody would be obliged to use them. Safety and security would be guaranteed. Managing the expectations of the locals and listening to their concerns presented another interessement device supporting the formation of the actor-network. While participation in the experiment was voluntary and focused on a tangible piece of technology, the inhabitants were still subjected to the framework of acceptance:

> Their imagined role is first as compliant consumers, helping to ensure the technology's success, and second as supportive citizens while the technology is being tested in plain sight. This speaks to two prominent AV policy agendas – support for innovation and enabling of testing. (Stilgoe & Cohen, 2021, p. 8)

Up to this point, the alliance of the project partners managed to overcome or work around most of the initial hurdles. The emerging actor-network seemed stable enough to move beyond the controlled space of the garage. Would the network survive the encounter with the chaotic reality of Seestadt? After all, "translation is a process before it is a result" (Callon, 1986a, p. 224).

In the next phase of the implementation process, the project partners step by step moved the buses to Seestadt and built the infrastructure of the test operation. A key event of this period took place in July 2018: For the first time, the vehicles transported passengers on a short route from the metro station to the Technology Center maintained by the Aspern Smart City Research (ASCR) project half a kilometer away (BMK Infothek, 2018). The public test also held several messages for the local population: These are the actual vehicles, they work securely, and we would like you to coexist with them in harmony. Besides showcasing the vehicles, the presentation also embedded the auto.Bus Seestadt project in the district's smart city narrative and corresponding infrastructure. The press statement emphasized the successful communication between the shuttles and a traffic light. The activities of the consortium not only attracted attention in Vienna: In July, Austria took over the presidency of the European Council and a delegation of the European Ministers of Transport paid the project a visit. The partners presented their research as pioneering autonomous transport in Europe, which positioned it as a flagship project in this sector.

What was there left to do after the first successful test in Seestadt? In the following months, the project partners continued implementing the necessary networked infrastructure described in subchapter 6.2 and refining the workings of the automation technology. One area that was improved upon was the communication between humans and machines. The screens integrated into the vehicles were a concrete outcome of this engagement. The terminal helped the operators understand how the ADS perceived the environment, while the screens facing outwards communicated information like the mode of driving or driving actions, like braking, to other road users. The AIT conducted research on the local traffic situation, the optimal design of the route, and the placement of stops. This involved the creation of models for simulating vehicle fleets and usage patterns. Empirical data on the local traffic conditions and driving behaviors was gathered by placing a technology called Mobility Observation Box (AIT, 2021a; AIT, 2021b) at an intersection in Seestadt (see the report by the AIT in Bundesministerium für Verkehr, Innovation und Technologie, 2020). This device automatically recognizes and classifies different road users with the help of an on-board camera and machine learning algorithms. While there is not a direct connection to the operation of buses, the auto.Bus Seestadt project provided researchers with the opportunity to test new techniques for data collection and analysis that could contribute to the vision of a real-time city in the future (Antenucchi, 2021; Kitchin, 2014).

But the area that probably was the most work intensive was the refinement and stabilization of the chain of automation, especially the automatic recognition of obstacles. Even though I still experienced many issues during fieldwork, the project partners improved the performance of the AVs significantly between their delivery in 2018 and my very first ride in the winter of 2019. As described in subchapter 6.2, the scanning of the environment, the creation and editing of maps, and the programming of the route were preconditions for the automated driving functions of the vehicles. Once the construction of this digital infrastructure was completed, NAVYA had to adjust the programing on site. The operator explains this process as follows:

> This [the programming] is then imported into the vehicle and then one lets the vehicle drive itself to see where there are still problems. And then it is programmed further. Then you delete various things in the program, so you tell the computer: Ignore that. Or pay more attention there. Or further to the left, further to the right. The exact programming really takes place in the vehicle. You really drive the vehicle. And then you can actually program meter by meter. There, 15 cm further to the right, so when we approach stops, that it really stops next to the curb where the doors should open, and things like that.[44]

44. „Des wird dann ins Fahrzeug einmal eingespielt und dann lässt man das Fahrzeug fahren und schaut, wo noch die Probleme sind. Und dann wird das weiter programmiert. Dann tut man verschiedene Sachen in dem Programm rausstreichen, also, das sagt man dem, dem Computert: Das ignoriere. Oder da mehr aufpassen. Oder da weiter links, weiter rechts. Also die genaue Programmierung erfolgt dann wirklich im Fahrzeug. Also da fährt man dann wirklich mit dem Fahrzeug. Und dann kann man wirklich Meter für Meter eigentlich programmieren. Da 15 cm weiter rechts, wenn wir Haltestellen anfahren, dass er wirklich genau knapp neben dem Randstein dort wo die Türen aufgehen sollen [stoppt] und solche Sachen.“

Still, the resulting program was static and inevitably contradicted the ever-changing conditions of the real world. One issue the partners encountered was linked to the vegetation along the route and the sensitivity of the obstacle recognition technique: Both during the live presentation at the TRA and later during tests in Seestadt, plants like grass, flowers, and trees prevented the AVs from driving. Over time, the growing vegetation and the scans had drifted apart. The additional biomass was identified as an obstacle. In this case, it was Seestadt that had to change, as the representative from the KFV explains: "The environment has also had to adapt and there are details that you somehow don't think about, like, I don't know, the cutting of the vegetation has to be kind of regular so the bus can go, or things like that."[45] The final report of the project mentions the pruning of 36 trees along the route as one of the challenges that had to be overcome (Bundesministerium für Verkehr, Innovation und Technologie, 2020).

Environmental conditions like snow, rain, wind, and dense fog posed a similar problem: If the weather got more extreme, the LiDAR sensors identified particles in the air as obstacles. Initially, NAVYA even suggested to only operate the shuttles in spring and summer to mitigate this problem. Wiener Linien disagreed because autumn and winter in Vienna were considered as relatively mild. However, the operators always had to take check the weather before the start of the operation. Strong rainfall could lead to a complete interruption of service, which was one of the many reasons for defining the project as a test rather than a regular bus line.

These examples highlight that the threshold at which the AVs recognized an entity as an obstacle was a major concern. As previously mentioned, the project partners experimented with additional sensors and infrastructures to improve the ADS in this regard: Both the three cameras added to the vehicle by the AIT and the I2V communication system developed by Siemens were attempts at stabilizing and extending the chain of automation. But these experiments never reached full implementation. The recognition of incoming vehicles at the crossing seemed promising and, in theory, would have allowed for automatic turns. But in reality, other road users proved too unruly, as the operator explains:

45. „Die Umgebung hat sich auch anpassen müssen und das sind auch so, so Details, an die man irgendwie nicht denkt, oder ich vorher niemals gedacht hätte, wie, weiß nicht, da musste der Grünschnitt muss irgendwie regelmäßig erfolgen, damit der Bus fahren kann oder solche Sachen."

> Of course, we have a problem: man. We do have a speed limit of thirty here in Seestadt. But if vehicles are coming from the left or right at a speed of fifty or sixty, until the bus starts moving, that's not going to work out. That's why we never put that in. Would work theoretically. Practically, man has to do the work. It's not yet possible.[46]

In this case, the re-assembly of Seestadt and the translation of actors into the actor-network of the test operation reached its limits. Some of the commuters in Seestadt ignored the pre-scriptions embedded in the local transport infrastructure and enforced their own de-scriptions, like driving at a much higher speed (Akrich, 1992). Thus, the technoscientists could not stabilize the links between the AVs and the supportive infrastructure at the intersection: Actors not directly associated with the network went off script, making their integration into the chain of automation impossible. Instead, the project partners had to rely on more reliable partners: the operators. The implicit frustration in the operator's statement relates to the attachments of automate driving as discussed by Tennant and Stilgoe (2021): The sometimes unpredictable behavior of human actors easily overwhelms automated systems. Their inflexibility could be mitigated by adapting infrastructures to their needs, for example by operating them on separate lanes, but the narration of autonomy assigns blame to other road users instead: They should be educated or controlled mores strongly. The dependence of AVs on strict traffic regulations might also develop into technological politics embedded in the artifacts (Winner, 1986), leading to changes in the general transport infrastructure.

All the outlined negotiations, trials, errors, fixes, workarounds, and compromises paved the way for the opening of the test operation on the 6th of June 2019. In the end, the project partners established a routine that was stable enough for the transportation of passengers on a daily basis. The associations between the involved actors had to be as durable as possible. Thus, the project partners tied "together all these scattered elements into a chain in which they are all indissociably linked" (Callon & Latour, 1981, p. 289). While the translation of actors is a slippery slope that can never be fully guaranteed, there are still strategies for making an actor-network more resilient: simplification, juxtaposition and black-boxing (Callon & Latour, 1981; Callon, 1986b). The technoscientists working on the network made use of these methods wherever possible. As outlined in subchapter 6.4, they juxtaposed the necessary human and non-human actors into the chain of automation.

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46. „Haben wir natürlich das Problem: der Mensch. Wir haben zwar hier eine dreißiger Begrenzung in der ganzen Seestadt. Aber wenn die Fahrzeuge mit fünfzig, sechzig von links oder rechts kommen, bis der Bus sich in Bewegung setzt, wird sich nicht ausgehen. Deswegen hat man das nie einfließen lassen. Würde theoretisch funktionieren. Praktisch tut der Mensch arbeiten. Ist noch nicht möglich."

This set of relations closely orchestrated the interactions between the involved actors and enforced a more or less strict logical sequence. To achieve the chaining of actors and interactions, the multiplicity and heterogeneity of the actor-network had to be simplified: “Each entity is thus reduced to a few properties which are compatible with the relationships established between the entities” (Callon, 1986b, p. 34).

What remained is a highly simplified plot: The bus drives automatically from station to station and picks up the passengers waiting there. The vehicle is able to follow its programmed path, detect obstacles, and stop in front of them. The operator watches over the operation of the bus and takes over control if needed. He also handles the interaction with the passengers and takes care of any other issue the bus cannot solve on its own. The operation is limited to a test. It is part of a research project, which involves several partners. These want to try out the technology and work on the future of automated transport.

Of course, this synopsis contradicts the complexity of the actor-network that I analyzed over the course of this chapter. It mostly ignores the networked and infrastructural characteristics of the test operation: From an ANT perspective, the bus neither drove itself, nor did it recognize obstacles, nor was it a self-contained artifact in the first place. But for the operation to work, the shuttles had to be simplified and black-boxed as much as possible. According to Callon and Latour, a “black box contains that which no longer needs to be reconsidered, those things whose contents have become a matter of difference” (Callon & Latour, 1981, p. 285). I would argue that most associations that made up the test operation were in between those two states: The translation of actors and the chain of automation did not have to be reconsidered every time the shuttle made another round. However, most of the used black boxes remained half open and some associations between actors remained relatively weak. As I learned throughout data collection, the world of Seestadt always had something up its sleeve that complicated matters: leaves, flowers, missing GPS coverage, bad weather, speedsters, construction sites – the list goes on. To some degree, these intrusions had to be expected. They formed an intrinsic part of the test operation and the chain of automation. It was the job of the operators to deal with errors and uncertainties, and in most cases, they resolved these issues in due time. Therefore, including this highly flexible human element into the chain of automation was an ingenious move by the project partners.

After one year of network building, it seemed like all the essential actors were successfully translated into the networked infrastructure of the test operation. The implementation of the autonomous shuttle buses into Seestadt was finished – at least in theory. Now it was time for the last phase of the project: the public test operation.

On Thursday, the 9th of June 2019, the project partners opened the operation of the two shuttles to the public. The very first passengers were local politicians who voiced their support and appreciation: Michael Ludwig, the mayor of Vienna, and Ulli Sima, city councilor for innovation, city planning and mobility. Press material linked the innovative character of the project to the city of Vienna as a driving force behind such developments. Sima also highlighted the high quality of the public transport services offered by Wiener Linien and stressed the importance of innovation in this sector. Thus, the project partners succeeded at gaining political support for the project and shaped visions of the future of mobility on the municipal level (Stadt Wien Rathauskorrespondenz, 2019). Vienna's smart city strategy explicitly mentions the adoption of automated driving as a shared mobility service, so the research project could be interpreted as a first step in this direction (Vienna Municipal Administration, 2019). The opening ceremony kicked off a successful half-year for the project partners: Local citizens and tourists, both from Austria and abroad, were eager to try out the technological novelty. The project received increased media attention.

But only a few weeks after the start of the test operation, there was an accident: A woman collided with one of buses, leading to the temporary suspension of the testing allowance and an investigation into the reasons for the accident. After reconstructing the course of events, all involved parties assigned blame to the pedestrian: She was wearing headphones and was looking at her phone when she walked into the already standing bus. The AV did what it was supposed to do and initialized an emergency braking on time. The pedestrian only suffered light scratches. Apparently, there was no doubt that this retelling of events was true. A reason for the high degree of certainty was the extensive data collection performed by the sensors of the Autonom Shuttle. The operator explained:

> NAVYA can really track it down to the second. Everything is recorded, every movement of the bus. And also, what it saw, so that really is documented precisely. We received several pages of documentation with pictures of where the bus recognized the situation, where the bus initiated braking.[47]

In the case of an accident, the project partners had prepared a detailed procedure for causal research using the collected data. In addition, the operator immediately called an

47. „NAVYA kann das wirklich sekundengenau nachvollziehen, das ist ja alles aufgezeichnet, eine jede Bewegung von dem Bus. Und auch was er gesehen hat, also das ist wirklich genau dokumentiert. Da haben wir mehrere Seiten Dokumentation bekommen mit den Bildern dazu, wo der Bus das erkannt hat, wo der Bus die Bremsung eingeleitet hat."

ambulance and the police to record the accident. This way, the project consortium successfully prevented any doubts regarding the innocence of the AV. Also, the stakes were low, as nobody got hurt. Only a week later, the case was closed, and the consortium was allowed to continue testing.

The incident holds several key insights regarding the state of the actor-network: First, the translation of actors proved durable enough to withstand a potentially catastrophic event. Second, the chain of operation worked reliably and prevented a real crash. Stopping in front of obstacles is central to the automation of driving, and with the support of the network, the AVs were quite good at it. Third, the project partners were prepared to defend the network against outside scrutiny, by proactively involving third parties and by providing an exceptional amount of evidence. This approach differs from reluctant responses by private companies to accidents involving their automation technology (Stilgoe, 2018; Stilgoe, 2020). In Austria, the AutomatFahrV holds the parties testing AVs responsible, so they are obliged to cooperate quickly and reliably. Fourth, the incident highlights yet another level of dependence on NAVYA's products and services. It also makes clear that the test operation was a complex sensory infrastructure that collected an unimaginable amount of data on public life. These interdependences underline both Graham's (2002) points on the splintering of urbanism and Antenucchi's (2021) analysis of the bordering practices enacted by smart city infrastructures. As outlined in subchapter 6.2, the networked infrastructure of the test operation reassembled existing infrastructures and new technologies into a specialized grid largely under control of the project consortium. Reflecting on the issues of ethics and morality in relation to autonomous vehicles (JafariNaimi, 2018; Jean-François et al., 2016; Nyholm & Smids, 2016), the incident shows that the theoretical discussion of these topics and the reality of automated driving are drifting apart. Experimental ethics or algorithmic morality did not play any role, and probably would not have played any in the case of an actual crash: The shuttle always initiated an emergency braking once it recognized an obstacle that was too close. The only morals it knew was stopping in front of other road users instead of running them over. If it failed to recognize another road user, which supposedly never happened, then the operator was responsible for braking in time.

But the most important takeaway is that the work of translation, and correspondingly, the implementation of the AVs into Seestadt, was successful. After the dust had settled, the buses and operators continued their rounds from Monday to Friday, except for bad weather. At one point, the stream of new visitors stopped and only very few people continued using the buses. With the onset of the pandemic, the number of passengers declined even further. Between April and May 2020, the operation was put on halt because of pandemic prevention measures, which led to the extension of the project runtime till 2021 (Bittermann, 2020; Wiener Linien, 2020). My very first encounter with the test operation in the winter of 2019 was probably towards the end of the initial peak, as I still encountered a group of tourists riding the shuttle.

The project received a lot of media attention throughout its runtime, which my interview partners highlighted as exceptional. Gaining this level of support was important to the project partners: The researchers from the AIT relied on the participation of interested citizens for conducting several studies on the interaction between the passengers and the bus, on usage patterns, as well as on personal sentiments towards the vehicles. Wiener Linien gained experience in running an automated public transport service under conditions similar to a regular bus line. In general, the public interest in the project was beneficial to all involved parties, as they were able to position themselves as innovators and pioneers in the promising field of automation at a national and international level.

On the 23rd of June 2021, the buses drove through Seestadt for the last time. All that remained of the test operation were small patches of fresh concrete and metal covers where once were stops. What conclusions did the project partners draw after three years of testing? The representative from Wiener Linien stressed the consortium's accomplishments while pointing out that the limitations of the automation technology are too severe for practical use:

> But the whole technology is actually still quite in its infancy, yes. Now we have grown along, the shoe size is a bit bigger if you compare it now. But we have not yet reached the point where we can say, okay, this can now be included in our operation as a fixed component.[48]

I want to highlight the metaphor of growth and infancy. As in previous statements, the partners anthropomorphized the technology and created a story of parents helping their child to grow up. But in the end, they had to accept that the bus-child is simply not ready yet. To some degree, this was a disappointment. The operator told me that initially there was hope that autonomous shuttles could be integrated into the fleet of Wiener Linien in

48. „Aber die ganze Technik steckt eigentlich noch noch ziemlich in den Kinderschuhen, ja. Jetzt sind, jetzt sind die, sind wir mitgewachsen, die Schuhgröße ist a bissl größer wenn mas jetzt vergleicht. Aber wir sind eigentlich noch nicht dort angekommen, dass man sagt, okay, das kann man jetzt als fixen Bestandteil bei uns in den Betrieb aufnehmen.“

the near future:

> Well, the thought was that if it had all worked out the way we wished, that one day the vehicle would really operate as a regular service. There at Seestadt, these two buses, that's a bus line and they operate there regularly.[49]

After having experienced the technology in the real world, all interviewees shared the conviction that the adoption of AVs on a large scale probably lies multiple decades in the future. In the final press release on the project, similar notions get voiced (KFV, 2021). All partners stressed that they gained valuable experience and would follow up on the topic of automated mobility in the future. To add to the metaphors used by my respondents: Not only the autonomous shuttles had grown up, but also the project partners. These coming-of-age stories are still ongoing, but the network of the test operation and the auto.Bus Seestadt project were always limited to a stop along the way. While the actor-network proved durable enough for the project runtime, its relative success was based on its temporary nature and experimental status. For a full implementation, the translations and associations that enabled automated public transport would have to become much more stable.

Taken together, these six subchapters presented an overview of how the test operation was implemented at Seestadt, what roles the individual partners played in the project, what actors this networked infrastructure encompassed, and how the automation of driving was accomplished through the chaining of actors. Thus, the goal of tracing this actor-network is completed. In the next chapter, I will employ the conducted empirical analysis to explore the meaning and relevance of the project along two central themes: the re-assembly of Seestadt into an ideal testing ground for automated driving, and the tension between offering a public mobility service while limiting the operation to a test and experiment.

49. „Naja, es wäre schon der Gedanke da gewesen, wenn das alles so funktioniert hätte, wie wir uns gewunschen hätten, dass das Fahrzeug wirklich einmal linienmäßig fährt. Einfach da in der Seestadt, diese zwei Busse, das ist eine Linie und die fahren da fix."

7 Understanding the Re-Assembly of Mobility in Seestadt

News coverage on the auto.Bus Seestadt project focused on the key events leading to the public test operation, the novelty of the technology, and the opportunity to experience automated driving in the real world. The necessary infrastructure and the difficulties posed by the automation technology were of secondary importance. But from a perspective interested in implementation, the Autonom Shuttle as a technological artifact was only the starting point and precondition for the sociotechnical process of realizing an experimental form of automated public transport in Seestadt. The state of the art of autonomous minibuses encompasses a limited number of products with very similar feature sets and affordances (Iclodean et al., 2020), which the operator also underlined. The project partners did not create a technological novelty, but tested a finished product delivered by NAVYA. Therefore, this study is not primarily interested in the vehicle's functions or the technology in general, but explores how certain automation features were realized in the specific context of the auto.Bus Seestadt research project. In their critique of the dominant focus on automation levels, Stayton and Stilgoe (2020) call for an alternative approach for making sense of automated driving applications: "less focus on the "driving task" and more attention to place, infrastructure, and road rules" (2020, p. 18). This chapter builds on the previous analysis of the test operation to contextualize its impact and relevance in relation to the goals of the research project and the location of the Seestadt quarter. There are two dominant themes that shaped the implementation of the shuttles: the status of Seestadt as an urban laboratory, which was further reassembled into an ideal test environment for automated transport; and the tension between offering a mobility service to the public while strictly limiting the operation to a test, as its quality and reliability could not be guaranteed.

7.1 Constructing an Ideal Testing Ground

This subchapter follows the proposed change in perspective: Instead of focusing on ever-increasing levels of automation and autonomy, the specific context of automated driving in society forms its main interest. I position the re-assembly of Seestadt into an ideal test environment as a major goal and material impact of the research project. As described in chapter six, the shuttle buses were only one component of the larger actor-network and networked infrastructure of the test operation. Integrating this network into Seestadt took the project partners multiple years. To make the automation feasible for daily use, they constructed an environment that accommodated the attachments of current automation technology (Tennant & Stilgoe, 2021). The location of Seestadt was of key importance in two regards: On the one hand, the partners were convinced that the quarter provided ideal conditions for the construction of the network. On the other hand, the technoscientists reassembled existing urban infrastructures with new elements to create a specialized grid for testing the autonomous minibuses.

The conviction of the participants that Seestadt is an ideal space for research and experimentation in the urban sphere was attributed to three main reasons: First, the quarter only recently made the jump from the drawing board into reality and is still under heavy construction, which lent the project partners increased flexibility during implementation. Compared to historically grown parts of the city, its structure is simpler, which made it easier to adapt Seestadt to the test operation. As the representative from Wiener Linien explained: "I have the advantage there that it is urban, but not as complex as when I imagine I would have to operate the buses on Kärntnerstraße."[50] The researcher form the AIT added: "We also had even more degrees of freedom there, also regarding the stops, the positioning, etc."[51] Likewise, the operator listed a series of very practical considerations for choosing the development area: "It is traffic-calmed, in all of Seestadt there is a speed limit of 30, we are not an obstacle there. And in the city center so many things would have to be considered: Traffic, parking violations, people, that would be too difficult, at least right now."[52] The new "city-within-a-city" (aspern. Die Seestadt Wiens, n.d.) in Donaustadt acted as a substitute for the actual chaos of urban life. The respondent from the KFV even described Seestadt as a "satellite city," expressing that Seestadt presents a more controlled and somewhat isolated version of Vienna. Its flexibility and relative simplicity were important considerations, as the ADS of the buses was severely limited. The decision for Seestadt presented a practical way of dealing with the attachments of AVs: "The question is not when self-driving cars will arrive, but where" (Tennant & Stilgoe, 2021, p. 15). Put differently: If the robot is not smart enough, the environment has to be simple

50. „Andererseits hab ich den Vorteil, dass ich ganz einfach urban urban dort unterwegs bin, aber einfach nicht so komplex bin, wie wenn ich mir vorstelle, ich müsste jetzt auf der Kärntnerstraße mit den mit den Bussen unterwegs sein." Kärntnerstraße is a famous shopping street featuring many luxury brands. It is located in Vienna's historical inner district, which is a confusing maze of one-way streets and pedestrian zones.

51. „Wo wir auch noch mehr Freiheitsgrade hatten, auch was die Haltestellen, Positionierung usw. betrifft."

52. „Aber es ist ein neuer Stadtteil, das ist einfach die Werbung und das ist beruhigt, verkehrsberuhigt, es ist in der ganzen Seestadt eine dreißiger Zone, wir sind dort kein Hindernis. Und in der Innenstadt, da kommen noch so viele Sachen dazu: vom Verkehrsaufkommen, Falschparker, Menschen, das wäre zu schwierig, momentan jedenfalls."

enough. In this regard, the project partners went beyond a simplistic understanding of the ODD (Stayton & Stilgoe, 2020) and interpreted the environment as an integral part of the network they were trying to build.

The second argument for realizing the project in Seestadt was its innovative appeal and status as an urban laboratory. The interviewee from the AIT pointed to the presence of institutions and organizations fostering innovative research. Among them are the Wien 3420 AG as a kind of custodian of the quarter, and the aspern.mobil LAB, who supported the project on multiple occasions. Furthermore, Seestadt is one of Vienna's flagship projects and attracts international attention. By moving the research to the proclaimed urban lab, the project partners profited from the heightened publicity of the quarter. Thus, the AIT researcher concluded that Seestadt provided them with all that they needed:

> Many visitors from other cities come here and take a look. Of course, it's favorable when you have a one-stop-shop, so to speak: Seestadt. The largest urban development area in Europe, with so many great new things and, of course, also an automated shuttle that drives around there. It's kind of the perfect place to do it there.[53]

This narrative of Seestadt as a one-stop-shop for research and development relates to the innovation paradigm in policymaking and the concrete sites of deficit construction, as explored by Pfotenhauer et al. (2019). Among other sites, the authors analyze recent innovation programs of the city-states Luxembourg and Singapore. These cases are especially interesting in relation to this study, as they in part fit Seestadt's status as a prioritized technological zone (Antenucchi, 2021) tailored towards innovative businesses and research. While I did not encounter the explicit construction of an innovation deficit for Vienna, there still was the underlying assumption that Seestadt provided much better conditions than the rest of the city.

The third argument for the preference of Seestadt over other parts of the city was linked to the first two and concerns its population. An idea shared by all interviewees is that an innovative and modern quarter like Seestadt would attract a young urban milieu open to innovation and forms of public experimentation. Regarding this demographic, the researcher from the AIT explained: "So these are the ones who like to participate in such

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53. „Es kommen sehr, sehr viele Besucher aus anderen Städten und schauen sich das dann an. Es ist natürlich dann günstig, wenn man so quasi ein, einen One-Stop-Shop hat: die Seestadt. Das Stadtentwicklungsgebiet, das größte Stadtentwicklungsgebiet Europas mit so und so viel tollen neuen Sachen und natürlich auch einem automatisierten Shuttle, das da herumfährt. Das ist quasi dann, bietet sich direkt an das dort zu machen.“

an experiment. They also have fewer fears of contact, fewer reservations, fewer worries associated with it, and so on."[54] The respondent from the aspern.mobil LAB recognized that there is a small group among the inhabitants referred to as early adopters, but that the population of Seestadt as a whole would come close to Vienna's mean. However, there would be a surplus of young families. The imagination of Seestadt's inhabitants as ideal test subjects and target group can be linked to the concept of acceptance in policy debates regarding potentially disruptive innovations, as well as to the deficit model of the public understanding of science (Stilgoe & Cohen, 2021). A common argument in those discourses is that the general public might resist and criticize new technologies. From this perspective, it was easier to interest the technology- and science-literate community of Seestadt in the project.

Taken together, these three unique features set Seestadt apart from other potential test locations in the city. When conceptualizing its appeal through assemblage thinking (Farías, 2012), the quarter already had been assembled as a smart city development region, urban laboratory, and center for technoscientific innovation before the project partners started reassembling it for the test operation. As shown in subchapter 6.2 and 6.6, they further implemented many changes and additions to the local infrastructure: the garage for charging and maintaining the AVs, stops demarcating the route, the reference GPS antenna on top of the metro station, experimental infrastructure-to-vehicle communication devices, detailed scans of the environment, and a fully programmed route leading through the digital representation of Seestadt. Thus, the auto.Bus project also contributed to the smart city narrative of the district (Söderström et al., 2014). There are strong synergies between the integration of urban infrastructures into the real-time city as a system of systems (Kitchin, 2014) and the future scenario of cooperative, connected automated driving (Martínez-Díaz et al., 2019; Yurtsever et al., 2020). Siemens seized the opportunity to test several products marketed towards such use cases. These experimental technologies could be useful for intelligent transport systems in the future.

But from the perspective of ANT (Callon, 1986b; Latour, 1996) and the concept of networked infrastructures (Graham, 2002), the test operation not only presented a technological system, but also a sociotechnical process that reshaped life in the district. Therefore, Seestadt should not be reduced to a static backdrop for the buses to drive through. To fully grasp the re-assembly of mobility, one has to take into account the

54. „Also das sind die, die gerade bei so einem Experiment gerne mitmachen. Sie haben auch weniger Berührungsängste, jetzt, weniger Vorbehalte, weniger Sorgen, die damit im Zusammenhang stehen und so weiter."

emergent quality of urban space:

> Similarly, the notion of urban assemblages understands that the urban is an emergent quality of the multiple assemblage process, which is not pre-existent in the streets, the buildings, the people, the maps etc. The city is thus not an out-there reality, but is literally made of urban assemblages, through which it can come into being in multiple ways. (Farías, 2012, p. 15)

According to this conceptualization, Seestadt comprises multiple overlapping and even conflicting assemblages. As described in subchapter 1.1, it is surrounded by a belt of construction sites that has been expanding the district ever since. Its work-in-progress status provided the auto.Bus project with a high level of flexibility. But it also led to difficulties, as the respondent from Wiener Linien recognized:

> Seestadt is growing like crazy. Which was also a challenge for us, of course, because we had a lot of construction sites along the way. But yes, that's how we've grown along with the city and with the, how shall I say, with the challenges that you simply have in the city.[55]

The project partners had to adapt the actor-network of the test operation to these shifts. The operator told me that they were standing on a big construction site when they searched for potential routes in the beginning of the project. At that time, the Lakeside Park Quarter where the bus went through had not been finished yet. On multiple occasions, the ongoing constructions hindered the automation of the buses, as changes to the built environment conflicted with the original 3D maps and the programming of the route. Updating the data was a strenuous process, as it required the presence of a NAVYA engineer and specialized equipment.

Still, the participants were convinced that it was easier to implement the test operation in this new and expanding development area than anywhere else in Vienna. They interpreted the ongoing, large-scale assembly of Seestadt as an opportunity to reassemble parts of the quarter into their own specialized grid (Graham, 2002). Returning to Seestadt's image as an urban lab and the experimental character of the research project, both assemblages reinforced each other despite their conflicts: The project consortium wanted to test the AVs under real-world conditions, which was challenging because of technological limitations and potential conflicts with other road users. Ideally, the ODD of the buses

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55. „Also die Seestadt wächst wie verrückt. Was für uns natürlich auch eine Herausforderung war, weil wir sehr viele Baustellen auf der Strecke hatten. Aber ja, so sind wir halt auch mitgewachsen mit der Stadt und halt auch mit den, wie soll ich sagen, mit den Herausforderungen, die man halt in der Stadt auch einfach hat."

would have been limited to a highly stabilized environment with as little dynamic factors as possible. The participants brought up airports and hospitals as examples of tightly controlled conditions in which autonomous shuttles could excel. In contrast, testing on public roads was much more difficult. In order to make the test operation feasible, they chose Seestadt as a location freed from many complexing factors typical of urban spaces. The displacement of the buses from the plant in France to the test track in Leopoldau and, finally, to the public roads of Seestadt presented a movement from one laboratory to the next. Throughout the implementation process, the scope and complexity of the experiment increased exponentially. Albeit Seestadt is not a laboratory in the conventional sense, as its borders are much more porous, it has been assembled in a very controlled way. There was very little historical baggage to consider.

The auto.Bus Seestadt research project further reassembled this emergent urban fabric to create an ideal testing ground for the autonomous bus shuttles. The living, breathing world of the quarter was much more chaotic than the test tracks of the DARPA challenges, which started the recent hype surrounding autonomous vehicles (Albert, 2019; Thrun, 2010). One could position the test operation as a more realistic Urban Challenge that took place more than a decade later. The project also reinforced sociotechnical developments and narratives already present in Seestadt, by adding to its computational environment and smart infrastructures (Antenucchi, 2021; Gabrys, 2016; Kitchin, 2014), and by underlining the district's innovative appeal through the testing of experimental automation technology. The test operation was an urban mobility experiment tailored to and profiting from its experimental urban environment. Both the district and the project were in a relationship of becoming-with, as the aforementioned metaphor by the interviewee from Wiener Linien expressed: "So yes, we have been growing along with the city and … with the challenges that you simply have in the city."

7.2 Experimentation and Operating

The tension between the creation of controlled testing conditions and the urge to implement the vehicles into the indefinite reality of Seestadt also defined the purpose and scope of the test operation: On the one hand, the partners used this networked infrastructure as an experimental setup for answering different research interests. On the other hand, the test resembled a regular bus line and provided locals and tourists with mobility. During its flexible schedule, anyone interested could hop in and out of the shuttles at one of the stations. From my own experience, I know that taking part in this experiment felt very similar to riding any other bus in Vienna. What stood out were the interactions between the operator and the machine as, as described in subchapter 6.4, as well as the slow speed and sometimes janky driving performance of the vehicles. In the case of the auto.Bus Seestadt project, experimentation with automated driving and the operation of a mobility service were intertwined. I argue that both practices reinforced each other: By framing the operation as a test while fulfilling a semi-regular schedule, the project consortium interested the public in the experiment while making the automation of driving feasible.

As already mentioned, the involved parties strongly disagreed that the shuttles presented a mobility service. The researcher from the AIT tried to distinguish what the test operation had to offer and what it did not:

> Let's put it this way, they [the buses] are now an offer that is there. But it's not really a public transport offer. It's an experiment. But there is no replacement, if, for example, it breaks down because of the weather, or because something is not working, or the battery is empty. Normally, Wiener Linien would have to provide a replacement. There is no replacement. It is not a regular service. It is simply a test. And yes, as long as it's not a finished service that you can rely on, it can't be more than an experiment and a test.[56]

There are two central aspects to consider in this statement: First, the respondent recognizes that the test operation provided a service to people: You could use the buses to go from A to B. Second, the interviewee denies that the AVs presented a regular public transport service because they were too unreliable. You could not depend on them, and the quality of service was not guaranteed. Accordingly, Wiener Linien (2020) clearly communicated that the AVs were limited to a test. The operator told me that the operation indeed had to be stopped regularly. Just days before our interview, the buses stood still three days in a row because the wind speed was above the operational limit of 60 km/h. Such a long outage would be unacceptable for a regular public transport offering.

As shown in chapter six, the ADS of the buses and the infrastructure of the test operation involved many affordances that had to be taken care of. In this regard, the findings by Tennant and Stilgoe (2021) are similar to the results of this study: The project partners as

56. „Sagen wir so, sie sind jetzt ein, ein Angebot das da ist. Aber es ist nicht wirklich ein ÖV-Angebot. Es ist ein Experiment. Aber es gibt wenn er ausfällt, z.B. aus Wettergründen oder weil gerade irgendwas nicht funktioniert oder die Batterie aus ist, gibt's keinen Ersatz. Normalerweise müssten die Wiener Linien dann einen Ersatz stellen. Gibt es nicht. Es ist nämlich kein Linienbetrieb. Es ist einfach nur ein Test. Und ja, so, solange es eben kein, kein fertiges Service ist, auf das man sich verlassen kann, kann es nicht mehr als ein Experiment und ein Test sein."

stakeholders in the automation technology were aware of its lacks, limits, and dependencies – its attachments – and included various coping strategies in the implementation. The re-assembly of Seestadt into an ideal testing ground was a central step in the formation of the actor-network.

Other important strategies were the labeling of the operation as a test and the combination of automated and manual driving modes. Even if one subscribes to the simplistic and deterministic differentiation of automation levels (SAE International, 2021; Stayton & Stilgoe, 2020), there currently is no stable implementation of level three automation (Yurtsever et al., 2020). In contrast to claims of full autonomy and automation present in the automated driving discourse, the project consortium clearly stated that the shuttles are not ready for regular use. Although the vehicles were still described as autonomous, the autonomy of the machine depended on the agency of the human operators to a large degree (Stayton, Cefkin, & Zhang, 2017). The project partners were aware of the complex and error-prone intertwinement of automation and manual intervention. They tested different means to increase the level of automation, like the use of additional cameras integrated into the bus, or the infrastructure-to-vehicle communication devices that could have informed the ADS about incoming vehicles. However, these augmentations were limited to proof of concepts and experiments not used during regular operation.

While the implementation of the buses into Seestadt was primarily conceptualized as a test and experiment, it also provided a service to users and passengers. One could reasonably expect the shuttles to operate according to their schedule, even if there were outages from time to time. In addition, the route was not serviced by other forms of public transport. As shown in subchapter 6.2, the project partners tried to find a route that “made sense”. One aim was to close a gap in coverage, even if the potential of the operation to do so was strongly limited. The researcher from the aspern.mobil LAB explained: “That was the logic behind the selection of Seestadt. So the approach was that these autonomous shuttles should in the future provide areas of the city with mobility, which have a low public transport quality.”[57] This statement relates to a specific use case for automated minibuses present across all interviews: bridging the first and last mile of transit. In the case of the auto.Bus Seestadt project, the vehicles transported passengers back and forth between the metro station “Seestadt” and the residential buildings. During fieldwork, I got the impression that the buses could have been useful to a subset of the local population.

57. „Also der Ansatz war, diese autonomen Shuttles sollen in Zukunft Bereiche der Stadt mit Mobilität versorgen, die sozusagen so a zu niedrige ÖV-Güteklasse haben.“

Indeed, the operator mentioned that the buses served a small group of regular customers, especially during the very first round at exactly half past seven in the morning.[58] Despite its continuous use by a handful of people, there is strong evidence that the test operation was not very practical. As the participant from the KFV pointed out, the flexible schedule was suboptimal for commuters holding a conventional nine-to-five job. The buses simply did not drive anymore after midday. Even if one caught the shuttles at the right moment, they drove very slowly along a short route. In most cases, walking was probably more efficient than waiting for the bus. These limitations impacted passenger numbers significantly after the initial peak. After trying out the AVs once or twice, there was little reason to keep using them. The operator hinted that barely twenty people a day rode the vehicles, rather less. These numbers come close to my experiences from fieldwork, as I barely encountered other passengers.

The tension between investing a lot of time and resources in the implementation of the AVs as a mobility offering while simultaneously limiting their potential to a relatively impractical test begs the question: Why did the project partners decide to operate the shuttles in public over an extended period even though they had to make so many compromises? What purpose did the actor-network and the networked infrastructure of the test operation serve? The results of this study suggest that the implementation of the test operation into Seestadt was an end in itself. It provided the project partners with the opportunity to test a very specific use case for automated driving technology without having to ensure its long-term viability. The participants shared the conviction that only a public test and the cooperation across different areas of expertise served their combined interests. Continued experimentation on a closed test track, like the one next to the garage in Leopoldau, would have defeated the purpose. The representative of Wiener Linien explained:

> Of course, you can just let the bus follow a route, it would probably also have worked if the bus simply drove in a circle and one never changed anything. It stopped in front of every obstacle. A lot would not have happened if the partners had not gone hand in hand and everyone had simply brought in their own expertise.[59]

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58. Officially, this was conceived as a test preceding the regular operation starting at eight o'clock. Nevertheless, the operators picked up people waiting at the stations during this very first round.
59. „Naja, das glaube ich, kann ich wieder zurückkommen zu dem Punkt, dass
man den Bus natürlich auch einfach eine Strecke abfahren lassen kann, ich kann einfach, hätt wahrscheinlich auch funktioniert, wenn der Bus ganz einfach im Kreis fährt und und änder nix dran. Der hat gestoppt vor jedem Hindernis. Es, es wär viel nicht passiert, wenn da die, die Partner nicht so Hand in Hand miteinander gegangen sind und und jeder sein eigene Expertise ganz einfach

The project partners combined their efforts to adapt the Autonom Shuttle for the operation in Seestadt. They were interested in whether and how the implementation of the technology into the real world could be achieved and optimized. The baseline performance of NAVYA's product under fully controlled conditions only formed the starting point of this endeavor. As described in subchapter 6.6, the different organizations posed different questions towards the test, but they all revolved around the interaction between the AVs and their sociomaterial embedding. The researcher from the AIT explained:

> Yes, also how the bus behaves in traffic, how other vehicles behave in relation to the bus. I can only find that out in a field test. I can't do that in the lab.

This statement points to a more general argument, which is one of the most dominant themes in the interview data: The partners pursued the project to collect data and experiences on the practical application of automated driving technology. Experimentation and the public operation were intertwined: In order to test the automated shuttles, the consortium created the networked infrastructure of the test operation and enrolled a large variety of human and non-human actors for the project. To make the operation feasible in consideration of its attachments, the partners limited the scope and ambitions of the daily operation to a test and positioned it as a temporary and unobtrusive supplement to the quarter. Of key importance for both processes was the previously discussed re-assembly of Seestadt into an ideal test environment.

Based on the analysis in chapter six and subchapter 7.1, I argue that the test operation not only tested the vehicles, but also the individual expertise of the project partners, their cooperation in the project consortium, legal frameworks and innovation policies, the urban infrastructures of Seestadt, the innovative character of the district, the operators, the acceptance and participation of the local inhabitants, as well as the curiosity and interest of tourists, allies, and third parties. Building on Pineda's (2012) analysis of the Transmilenio bus system and the concept of arenas of development (1999), the auto.Bus project provided a cognitive space in which all these different actors-networks negotiated automated transport as a future scenario for urban mobility. The test operation was of key importance for this endeavor.

In Callon's case study (1986b), the Electricité de France positioned the véhicule électrique as "a passageway through which all the other entities that make up its world must pass"

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einbracht hat."

(1986b, p. 26). In a similar vein, the test operation served as the central obligatory passage point of the auto.Bus Seestadt project, binding the addressed actors to their respective roles in the actor-network. The translation of actors served the goal of implementation: Just like a group of scientists tried to adapt the technique used in Japan for the cultivation of scallops in St. Brieuc Bay (Callon, 1986a), the project partners imported the autonomous minibuses from Lyon to Vienna, trying to adjust the technology to the conditions in Seestadt. Callon remarks that "to translate, then, is to oblige an entity to consent to detour" (1986b, p. 26). In my case, the project partners persuaded their allies to move to Seestadt or relocate inside its borders. Their efforts were fruitful, as the quarter's re-assembly succeeded despite its issues and inconsistencies.

Reflecting on their experiences, the partners remarked that the buses are not ready for regular use and that the time frame for adopting automated buses remains unclear (KFV, 2021). Initial hopes of integrating the shuttles into Vienna's public transport network in the near future were quickly diverted. Nevertheless, the participants deemed the project a full success. There was an overarching story serving as a link between the different actors of the network, a kind of bildungsroman and sociotechnical vision that gave the project meaning beyond its fleeting material impact: the coming of age of the bus. This metaphor can be used to interpret every aspect of the auto.Bus Seestadt project:

The automation technology integrated in the minibuses is still in its infancy. In Seestadt, the project partners adopted such a vehicle from its creators in France. They acted as foster parents and helped the bus-child to make its first baby steps towards adolescence. It was special – a kind of robot. These robots are promised to drive better than any human in the future. But in the beginning of the project, it was unclear whether this particular child could drive at all. A team of experts and scientists monitored its every move, taking notes for future analysis and supporting the robot in every way possible. The operators watched over the bus-child like a parent teaching a teenager how to drive, ready to grab the wheel at any moment. Months and years passed, and the shuttle grew in parallel to its surroundings. Urban infrastructures and the local population got used to its presence. Over the course of the project, the bus underwent many trials, leading to greater self-confidence. A novice driver like the AV might take any opportunity to practice, giving parents, friends, and colleagues a lift. The test operation provided the bus-child with many such opportunities, day-in, day-out. Even strangers asked the robot to drive them, mostly out of curiosity. Some of them were suspicious in the beginning, but the foster parents of the child told them not to worry. The operators were patient *teachers, ensuring that it drove safely. Still, nobody could expect an inexperienced driver to perform on the level of a professional. If you wanted to arrive on time at an important meeting, asking this tween probably was not a good idea. Therefore, the operation in Seestadt remained primarily a test and an experiment. The bus-child never fully grew up, but its foster parents were proud of its development. They collected a large amount of data and experiences that would help them raise the next generation. After the project ended, the bus went back to France. Vienna was only a milestone in its evolution.*

This story spoke to all the addressed actors, supported their translation, and gave meaning to the network. Of course, this is a highly reductionist account reconstructed by me as an external researcher. But as I already showed in the analysis, the project partners tried to simplify the associations between the actors and black-boxed them (Callon & Latour, 1981) to stabilize the network. Still, errors and failures formed an intrinsic part of the operation. Tennant and Stilgoe (2021) conceptualize three major strategies used by developers of AVs for coping with the attachments of the technology. Based on the participant's accounts, the project partners employed similar strategies for the implementation of the test operation:

The urge to gather as much data as possible over multiple years of public operation speaks to a brute force approach to problem solving. The collected data was used for models and simulations, and for optimizing the chain of operation. More data and more computation would lead to a smarter machine. The experimentation with additional cameras for object recognition was a step into this direction: In the future, automated shuttles would not just stop in front of any obstacle but differentiate between different kinds of entities and go around them. But as the ADS was the intellectual property of NAVYA, improvements on the software level were limited.

The second strategy was the restriction of the operation to a clearly defined ODD suitable to the capabilities of the ADS: a short route through the relatively simple urban environment of Seestadt. The quarter was also adapted to the limitations of the technology. As Tennant and Stilgoe note, there is an increasing pressure to reorganize space according to the technically defined ODDs of automated systems. In the case of the auto.Bus Seestadt project, the partners recognized that the real world is largely beyond their control. Devices like the displays on the vehicle's front and back, the e-ink displays on some of the stations, as well as the operators, were ways of communicating with other road users, potentially influencing their behavior. Still, some actors refused their enrolment in the network, for example by speeding or by blocking the path of the bus.

The third strategy fully embraced the adaptation of reality to automated driving. Accepting the attachments of AVs and restructuring the world to accommodate them appeared as a practical solution for realizing the technology. The creation of a specialized infrastructural grid for the shuttles, as well as the introduction of the operators as a new kind of professional, can be attributed to this strategy. While all participants saw the adaptation of society to automation as inevitable, they were critical of the expected developments and ramifications. Anticipatory regulations, like the AutomatFahrV, and publicly funded research projects, like the different test operations of autonomous minibuses in Austria, were seen as important measures for ensuring the equitable and sustainable implementation of automated driving technologies. From this perspective, the auto.Bus Seestadt project appears as a form of public experimentation, which Stilgoe (2020) proposes as an alternative governance approach to the techno-deterministic model of disruptive, privatized innovation. Experimental regulations like the AutomatFahrV would enable the directed testing of emergent technologies instead of leaving the political aspects of innovation to the private sector.

After having pursued these different strategies over two years of operation, the project partners concluded that the dream of automated driving lies multiple decades in the future. Aside from testing purposes, the use of AVs on open roads would not make sense at the moment. Results from experiments like the auto.Bus Seestadt project could be used by policymakers and service providers to define the role of automation for mobility and transport. After having completed their research in the public interest, the participants passed back the ball to the private sector. As the representative from Wiener Linien suggested: “In the meantime, so to say, the homework for the manufacturers is simply to push the development forward and, as a vision for the future, on demand autonomous electrical vehicles covering, for example, the first and last mile, or simply gaps in the network.”[60] The researcher from the AIT underlined: “And then, the experiment with shuttles in Seestadt is over. So, we took a look at it, got to know the teething troubles, and now I think we’re waiting until there’s a market-ready product.”[61]

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60. „In der Zwischenzeit, quasi, ist sozusagen die Hausaufgabe für die, für die Hersteller einfach diese Entwicklung hier voranzutreiben und als Vision dann halt in Zukunft on demand autonome, elektrisch angetriebene Fahrzeuge, beispielsweise First und Last Mile, oder Lücken ganz einfach im Netz hier abzudecken.“
61. „Und dann ist das, ist das Experiment Shuttles in der Seestadt aber auch vorbei. Also, dann hat man sich das mal angeschaut, hat die Kinderkrankheiten kennengelernt und wartet jetzt dann glaub ich drauf, bis ein marktreifes Produkt da ist.“

These statements suggest a clear division of labor between the public and service providers on the one side, and private innovators and manufacturers on the other side. The former would test the prototypes provided by the latter, and then the private sector would refine the product to fit the needs of the public sector. This sequence appears pragmatic and outcome-oriented. It also highlights the synergies between experimentation and the public testing of new technologies. But the current field of automated driving encompasses developments that contradict the logic of manufacturers catering to the needs of the public: Software-focused companies like Google, Tesla, Uber, and Baidu increasingly challenge the traditional automobile industry. The division between manufacturing and service is also becoming more porous, as the advent of a fully automated robotic driver would allow IT and car companies to become transport service providers without the need for massive infrastructural investments or human workforce (Albert, 2019). To sum up this argument: Private companies investing in automation technology also follow their own interests, and these might not line up with the public interest. This tension has important implications for the current operations of AVs, as Tennant and Stilgoe highlight:

> A temporary apparatus of devices and social conditions currently supports AV trials: safety drivers behind the wheel, public roads as test sites, dedicated infrastructures, but also deregulation, exculpation and financialization. This situation grants AV developers temporary freedom from having to consider their attachments, but parts of it could become permanent, forcing the world to adapt to AVs rather than the other way round. (2021, p. 19)

In the case of the auto.Bus Seestadt project, the adaptation of technology and society went both ways. The project was an opportunity to conceptualize the role of automated transport in society by involving a broad spectrum of stakeholders. But it was still limited to an experiment under ideal conditions, lending a degree of freedom and support to the shuttles that would be unfeasible and uneconomic under most circumstances. The members of the project consortium proclaimed that the technology should become much more flexible and adaptive to the real world, but it remains to be seen how society and technology will be related to one another in the future of automated driving.

8 Conclusion: Anticipating the Future of Automated Public Transport

As part of the auto.Bus Seestadt project, two autonomous minibuses operated in Vienna's newly built housing district Seestadt between June 2019 and June 2021 (FFG Projektdatenbank, 2017; Wiener Linien, 2020; Wiener Linien, 2021b). This study investigated how the six project partners implemented the test operation of the AVs into Seestadt, leading to the re-assembly of mobility in the quarter. The posed research questions were answered by conducting qualitative interviews with personnel of the partnering organizations and the aspern.mobil LAB as a third party, as well as autoethnographic fieldwork in Seestadt. By employing actor-network-theory as an analytical lens (Callon & Latour, 1981; Callon, 1986a; Callon, 1986b; Michael, 2017), the implementation of the AVs was conceptualized as the construction of a network capable of automating public transport. While the technological artifacts of the buses presented an important starting point and precondition for the project, they would have been helpless without the support of a complex sociotechnical network. As the analysis showed, the test operation and the urban environment of Seestadt were deeply intertwined. The partners reassembled existing urban infrastructures and added new sensors, network connections, and datasets to create a specialized networked infrastructure tailored to the affordances of the automated driving system (Farías, 2012; Graham, 2002; Müller, 2015; Tennant & Stilgoe, 2021). In the following subchapters, I will reflect on my findings in more detail and offer my final conclusions to the conducted case study.

8.1 Recognizing the Limits of Automation

Self-driving automobiles have been promised to be just around the corner for decades, but the availability of AVs as commodity goods remains science fiction (Albert, 2019). The two minibuses operating in Seestadt were among the first materializations of the technology open to the public. Anyone interested could hop in and experience how the proclaimed future of mobility feels like today. The experiment also provided me as a researcher with the opportunity to explore the material practice of operating an automated bus line. The second subquestion aimed at identifying the actors involved in the automation and understanding the capabilities and practical limitations of the system.

Current technical discussions of AVs move away from the claim of autonomy, conceptualizing them as automated driving systems (Martínez-Díaz et al., 2019; SAE

International, 2021; Yurtsever et al., 2020). These systems are not self-reliant, but depend on the interaction between the different software and hardware components of their architecture. Taken together, these modules form a pipeline capable of automating certain aspects of driving. As no there is no system capable of full automation, all implementations are more or less limited. The widely used SAE taxonomy (2014; 2021) differentiates the level of automation on a scale from zero to five. The Autonom Shuttle by NAVYA fulfilled the requirements of level three conditional automation. According to the formal definition of this level, the ADS controls the vehicle's movements through traffic, monitors the environment, and reacts to changes if necessary. But there still has to be a human driver ready to take over control. If one solely focuses on the abstract definition of automation levels, it seems like the buses were already highly automated and only two steps away from reaching full automation. However, the empirical study of the test operation revealed that it was much more limited. At first glance, the vehicles seemed to drive themselves, albeit at very low speed. But to achieve this level of automation, the ADS heavily relied on the human operator present in the vehicle, as well as on the support of the mostly invisible infrastructure.

According to the taxonomy by the SAE, the operators were defined as fallback-ready users, meaning that they had to take back control from the system if the automation failed or reached its limits. In the case of the test operation in Seestadt, this exception to the rule of automation occurred constantly. At every intersection and at every stop, the operators pressed an on-screen button to pause or resume the automation. Furthermore, parts of the route had to be driven manually using an XBOX controller. The need for constant intervention was rooted in the limited capabilities of the automation system: As one interviewee put it, the AV strictly followed the invisible rails of its programming, unable to diverge from its path or assess traffic situations, like deciding whether it is safe to make a turn or not. The system was capable of only a single reaction to changes in the environment and the actions of other road users: abruptly stopping in front of entities crossing its path.

The limited automated driving functions of the buses are closely related to their operational design domain. As shown in the analysis, the ODD encompassed many more aspects than the general area of Seestadt and the specific route. It was also bound to the digital and material infrastructure the AVs depend on, confirming the critique that technical descriptions of the ODD externalize the conditions for automated driving (Stayton & Stilgoe, 2020). The most important prerequisite for the operation was the programming of the route, which in return required the translation of the environment into a three-dimensional point cloud map. NAVYA engineers first scanned the surroundings using a vehicle equipped with LiDAR sensors. Then, they heavily edited this data and programmed a path through the map for the vehicles to follow. For localization, the buses depended on GPS, an additional reference antenna, the maps, as well as on the sensors integrated into the vehicle (Levinson, Montemerlo, & Thrun, 2008; Sun et al., 2017). As the analysis of the chain of automation revealed, the relations between the AVs and the networked infrastructure were inflexible. Even small changes to the built environment of Seestadt broke the automation, as the maps and the programming of the buses became obsolete. The automatic recognition of obstacles was plagued by false positives, because the ADS could not differentiate between different types of entities, leading to emergency braking in front of static objects.

Taking into account these limitations, the abstract definition of automation levels did not line up with the reality of automated driving. The semi-regular transportation of passengers was only possible by including the operators as highly flexible human actors. The requirements of this job were high: All operators were experienced bus drivers and received additional training by NAVYA. Rather than acting as a crutch for the AVs to lean on (Stayton & Stilgoe, 2020; Tennant & Stilgoe, 2021), they were deeply engaged in the operation, constantly translating between changes in the real world and the inflexible actions by the non-human actors of the network. Therefore, automated driving was not a feature of the Autonom Shuttle, but a social practice (Stayton, Cefkin, & Zhang, 2017) dependent on the cooperation between the human and non-human actors of the test operation and the associated infrastructures, as well as on the constant negotiation between the actors of the network, the ever-changing world of Seestadt, and other road users. While the AVs obtained a limited form of agency and autonomy through the chain of translations, the findings of this study show that the idea of replacing human drivers with a combination of hardware and software is not grounded in reality (Stilgoe, 2018; Stilgoe, 2019). Instead, the irony of automation (Bainbridge, 1983) is that an advanced ADS depends on a highly skilled human individual as a partner, as well as on the support from a specialized networked infrastructure.

8.2 Adapting and Adapting to Automation

The public test operation was the outcome of a long series of translations. After the delivery of the vehicles in spring 2018, the project partners started the implementation process. Over the course of approximately one year, they moved the vehicles from a closed test track next to the bus garage of Wiener Linien to their final destination in Seestadt. The main research question and first subquestion aimed at understanding how the project partners reassembled the quarter for the experiment and how they adapted the automation technology and the local infrastructures to one another.

As already argued, the ADS of the shuttles was severely limited. In order to make the operation feasible, there were several compromises regarding the performance of the buses themselves: Due to their abrupt and unpredictable braking behavior, the maximum speed was limited to around 16 km/h. For the same reason, all occupants had to be seated, which greatly reduced the maximum capacity of the vehicles to ten passengers. In light of pandemic prevention measures, this number was further reduced to only two people, plus the operator. Weather conditions like strong wind, rain, fog, or snow impacted the performance of the integrated sensors (Schoettle, 2017), making the automation of driving impossible. These technical limitations already made the shuttles less effective compared to other means of transport.

Of utmost importance for the feasibility of the operation was its location: Seestadt. The proclaimed smart city development area (aspern. Die Seestadt Wiens, n.d.) and newly built housing district at the fringes of Vienna appeared as an ideal test site. The local road network is relatively simple compared to historically grown parts of the city and the whole quarter is traffic-calmed. On the one hand, there were fewer variables to account for in the chain of automation; while, on the other hand, the AVs did not disrupt the flow of traffic too much. As Seestadt was and still is under construction, it also lent increased flexibility regarding the route and the placement of stops. Furthermore, the smart city narrative of Seestadt (Söderström et al., 2014) and the innovative appeal of the research project reinforced each other, guaranteeing political support and international publicity. Other concerns were issues of acceptability and trust in relation to the public testing of AVs (Graf & Sonnberger, 2020; Hampel et al., 2018; Millonig & Fröhlich, 2018; Pfotenhauer et al., 2019; Stilgoe, 2020; Stilgoe & Cohen, 2021). The population of the quarter is younger than Vienna's mean, which the partners interpreted as a sign of the increased openness of its inhabitants towards science and technology. Because of the outlined characteristics, Seestadt presented a unique opportunity to the project: Here, the partners could test the vehicles under real-world conditions while enjoying a relatively high level of control.

The quarter provided a good starting point for the implementation. Furthermore, the partners reassembled parts of the district and added new infrastructural elements to make the automation of public transport possible. The most apparent additions were the stops delimiting the route of the buses. The decision on the final route was influenced by several factors. While the shuttles did not present a regular mobility service, the idea still was to bridge the first and last mile of transit, feeding passengers back and forth the metro station (Becker, Kirchberger, Pühringer, & Stumfol, 2020; Millonig & Fröhlich, 2018). Along the route, the buses encountered different traffic situations, like a rotary and an uncontrolled intersection, which was interesting for testing purposes. Due to the limited computational power and battery capacity of the vehicles, the route was only around two kilometers long, leading to a small service area and the dense distribution of the six stops. As the drive to the main bus garage of Wiener Linien would have taken too long, the partners built a small garage underneath the bridge of the metro stations to charge and maintain the vehicles. The newly built infrastructure also included elements specific to automated driving applications. A reference antenna on the roof of the metro station allowed the buses to precisely locate themselves. At one intersection along the route, Siemens deployed an experimental camera system that could have informed the AVs about incoming vehicles, in theory making the automation of turns possible (Siemens, 2020; together.magazin, 2019). In practice, however, this integration proved too unstable because of speeders and was not fully implemented. The most complex dimension of the networked infrastructure was the three-dimensional map of the environment and the programming of the vehicles. As these components were provided by NAVYA, the project partners in Vienna were reliant on the actors located in France.

Even after the initial re-assembly of Seestadt for the test operation was completed, the infrastructure required ongoing efforts and adaptations. The most significant issues were changes in the environment, as these made the digital representation of the built environment and the programming of the buses outdated. In this regard, the ongoing construction of Seestadt was also a major disadvantage, as construction sites along the route obstructed the path of the vehicle multiple times. Such changes either required repeated scans and programming by NAVYA, which lead to increased workloads and delays, or segments had to be driven manually by the operators, thus undermining the goal of automation. But also small shifts like growing vegetation confused the ADS. In this case, Seestadt had to adapt to the inflexibility of the system and the trees along the route were pruned more regularly. While the test operation introduced a variety of new components to Seestadt, it was also connected to existing infrastructures, like GPS and the cellular network. If these services were unavailable, the buses stopped immediately, highlighting the connected nature of automated driving.

By adding new actors and networked technologies to the district and by reassembling existing urban infrastructure into the test operation, the project partners created a specialized grid that associated heterogenous actors across space and time (Graham, 2002; Farías, 2012): The route and the stops connected previously unserved locations to the public transport network. The material fabric of the quarter was overlaid with a digital scan of the environment. The physical location of the buses was synchronized with satellites in the orbit and the reference antenna on top of the metro station. Sensors integrated in the environment and the vehicles formed an elaborate sensing network (Antenucchi, 2021; Gabrys, 2016; Kitchin, 2014) which constantly scanned the environment for both known and uncharted elements.

The enacted translations, transformations, and workarounds opened up Seestadt for the test operation. These changes highlight that the partial automation of driving and the limited autonomy of robotic vehicles require new infrastructural investment, as well as the availability of existing transport networks, network connections, and city services. AVs encompass attachments on multiple levels (Tennant & Stilgoe, 2021), and as the case of the auto.Bus Seestadt project shows, most of these attachments can only be accounted for by adapting the environment and the routine of the operation to the capabilities and affordances of the automation technology.

8.3 Helping Automated Minibuses Grow Up

As a last step, I want to reflect on the societal context of the auto.Bus Seestadt research project, the motives of the project partners for conducting the test operation, and the broader relevance of my findings. In 2016, there was a unique window of opportunity for conducting research into automated driving. The Ministry of Transport introduced policies and funding schemes directed towards innovation in this field (Federal Ministry for Transport, Innovation and Technology, 2012; Federal Ministry of Transport, Innovation and Technology, 2016) and new legislation made the testing of automated vehicles on public roads possible for certain use cases, among them autonomous minibuses (Legal Information System of the Republic of Austria, 2016). These developments were the impetus for the auto.Bus Seestadt research project. Wiener Linien and the AIT were eager to try out the technology and took on leadership roles. To fulfill formal requirements and get the necessary expertise, they interested the other four project partners in joining the project consortium. All involved organizations have stakes in automation technology, although their individual interests differed. By posing the third subquestion, I explored their motives and contributions:

Wiener Linien as public service provider wanted to test AVs as a potential addition to its services offerings. For the researchers of the AIT, the test operation presented a unique experimental setup for answering different research questions, mostly in relation to computer vision, user studies, and traffic modeling. The KFV and TÜV Austria are both expert bodies in the field of vehicle and road safety. By attending to the legal and formal questions of the operation, they expanded their expertise in relation to autonomous driving. Siemens (2019; UIV Urban Innovation Vienna GmbH, 2018) is a stakeholder in the smart city infrastructure of Seestadt and provided additional sensing technologies to the operation (2018a; 2020). NAVYA as private innovator supported the project with the two vehicles and essential services. The aspern.mobil LAB was not part of the consortium but supported the project because of its research interest in mobility and participation in Seestadt. Associated researchers established communication with the local population.

The common interest among these actors was the testing of autonomous minibuses as a potential use case for automated driving. The test operation in Seestadt served as the central interessement device and obligatory passage point for translating all the different actors into the network. If they wanted to take part in the heralded future of autonomous driving, they had to move to Seestadt and contribute to the re-assembly of mobility. As two years of public operation showed, the creation of this actor-network was successful and proved stable enough to withstand the many trials posed by the sometimes chaotic reality of Seestadt.

In their final press statement (KFV, 2021), the project partners concluded that the technology is not ready yet for regular use. My own experiences in riding the buses affirm this judgement, at least if one compares their performance to a conventional vehicle driven manually by a human. The test operation was impractical for daily use and was never positioned as a regular service. After the initial interest in the experiment, passenger numbers dropped significantly, and the operators were alone in the vehicles most of the time.

Why then did the partners invest all the time and resources in the public operation? A closed test, like the small track next to the bus garage in Leopoldau, would have been far easier to implement. As the results of this study show, the motivation behind the test operation was to collect data and experiences on using the shuttles under conditions that could present a sensible use case in the future. All participants were convinced that only a field test over an extended period of time served this goal.

Rather than leading to major breakthroughs, the project encompassed a series of small improvements and practical compromises. To conceptualize their accomplishments, the participants repeatedly used metaphors and anthropomorphizations: They helped the bus to grow up. Throughout its journey, it became more independent and self-assured. With the ongoing support by the project partners and the infrastructure, it was less frightened by the outside world, and less confused. Nevertheless, the bus is still in its adolescence and has a lot to learn before it is ready to transport passengers regularly. By accompanying the development of the bus, the project partners gained valuable experiences that would be useful for raising the next generation of autonomous vehicles. The research project was limited to a stop along the way to automated driving, and after having given feedback to policymakers and manufacturers, they would wait for more mature products and policies.

The implementation of the test operation into Seestadt and the efforts of the project partners in building this actor-network and networked infrastructure hold several key insights regarding the social dimension of automated driving and its role in society. The dominant narrative of ever-increasing levels of autonomy and automation, and the idea of replacing human drivers with a robotic system are detached from reality (Stayton & Stilgoe, 2020; Stilgoe, 2018; Stilgoe, 2019; Stilgoe, 2020). The irony of automation (Bainbridge, 1983) is that AVs are increasingly dependent on highly skilled human individuals (Stayton, Cefkin, & Zhang, 2017; Tennant & Stilgoe, 2021) despite fitting as much computing power and sensors into each vehicle as possible (Albert, 2019; Thrun, 2010). The minibuses used for the auto.Bus Seestadt project relied on human operators, detailed maps, manual programming, data connections, and sensory networks. These interdependences underline that AVs are not only connected devices, but hybrid beings made up of associations between numerous heterogenous actors. Automation does not eliminate the social aspect of driving but leads to new complexities (Tennant & Stilgoe, 2021). Both the fallback-ready human inside the vehicle and other road users have to account for the agency of the robotic system, requiring trilateral negotiations and consent. In a similar fashion, transport infrastructures will need to adapt to automation in the future, necessitating significant investments.

The results of this study confirm the analysis by Tennant and Stilgoe (2021) that autonomous vehicles are defined by their attachments. For the automation to work, processes of adaptation are inevitable. The question is which direction the necessary sociotechnical transformations will take. While some private companies call for deregulation and try to adapt society to their products (Stilgoe, 2018; Stilgoe, 2020), publicly funded research projects are an opportunity to consider the sociopolitical implications of automation. By having examined the re-assembly of Seestadt for the test operation, this study contributes to STS research on the concrete reality of automated driving. It revealed how the technology's attachments were accounted for in this particular case.

In contrast to narratives of creative destruction (Joly, 2019) still dominant in the discourse of automated driving, the project partners positioned the test operation as a participatory experiment and a potentially useful addition to the district. They reassembled parts of the quarter to make the operation feasible, but they took care not to cause any major disruptions. The scope and ambition of the project were strictly limited, which helped to manage expectations accordingly. As initial concerns by a subset of the local population showed, there is public awareness regarding the ramifications of automated driving. Policymakers, researchers, and private innovators are responsible for answering to these concerns in relation to concrete use cases rather than expecting unconditional acceptance and participation from the public (Stilgoe, 2020; Stilgoe & Cohen, 2021). The interests, needs, and concerns of citizens are not a barrier to innovation, but should act as a compass for navigating the development and implementation of AVs into society.

Despite the public operation, the re-assembly of mobility was still a test. The constrained urban fabric of Seestadt acted more as a placeholder for the city than having been representative of the challenges AVs will face when operating in open traffic in the future. As the conclusion of the project partners revealed, the use of automated shuttles for public transport under these circumstances is neither practical nor justified. The experiences from the experiment hold important insights into how the attachments of AVs could be resolved in the future, but the main problem of making automation work in the real world remains. Reflecting on my findings, I got the impression that the environment and use cases we expect AVs to work in are the most important consideration for their implementation. Even in its current state, automation technology could perform well under much more strictly controlled conditions. So rather than asking when, the question is how and under which conditions AVs will become part of mobility infrastructures (Stilgoe, 2019; Tennant &

Stilgoe, 2021). Stilgoe (2021) argues that the state should take in an active role in governing innovation to ensure that the technology is being implemented in a sustainable and equitable manner. In Austria, experimental legislation and directed innovation programs initiated a first wave of research projects oriented towards this goal. It will be interesting to see whether the first round of test operations will lead to another, and whether the use of minibuses for a first/last mile scenario persists. Technological advances will definitely ease the transition towards automated transport, but the societal discussion of the conditions for automated driving is the most important step. Replacing private cars with private AVs neither seems feasible nor desirable considering the crisis of automobility.

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Table of Figures

Appendix

Abstract Deutsch

Diese Arbeit untersucht die soziomaterielle Praxis des automatisierten Fahrens, ihre Limitierungen und soziale Dimension anhand einer Fallstudie. Im Stadtentwicklungsgebiet Seestadt fuhren zwei autonome Kleinbusse im Rahmen eines öffentlichen Testbetriebs entlang einer kurzen Route. Das auto.Bus Seestadt Forschungsprojekt wurde von einem interdisziplinären Forschungsteam bestehend aus sechs Organisationen und Firmen umgesetzt, darunter der Verkehrsbetrieb Wiener Linien und das Austrian Institute of Technology. Ziel dieser Masterarbeit ist es zu verstehen, wie die Projektpartner die Shuttles und das Wohnviertel im Rahmen der Implementierung aneinander angepasst haben. Basierend auf klassischen Akteur-Netzwerk Theorien und verwandten Ansätzen zur Erforschung von urbanen Räumen und Infrastrukturen werden die Projektpartner als Erbauer des Netzwerks interpretiert, die bestehende Infrastrukturen mit neuen Akteuren und Technologien zusammensetzten und so die vernetze Infrastruktur des Testbetriebs erschufen.

Um die Routine des automatisierten Fahrens zu verstehen, führte der Autor autoethnographische Feldarbeit in der Seestadt durch und fuhr mehrmals mit den Bussen. Zudem führte der Autor fünf qualitative, problemzentrierte Interviews mit Vertreter_innen der Projektpartner und des aspern.mobil LAB als externen Partner, sowie mit einem der Operatoren. Die Ergebnisse zeigen, dass Automatisierung keine statische Funktion autonomer Fahrzeuge ist, sondern das Resultat von Übersetzungsarbeit und der Kooperation zwischen menschlichen und nicht-menschlichen Akteuren. Die Seestadt als Smart City Entwicklungsgebiet stellte einen günstigen Ausgangspunkt für das Projekt dar und wurde von den Partnern in eine ideale Testumgebung umgewandelt. Der Transport von Passagieren nach einem flexiblen Fahrplan und das Testen von automatisierten Fahrsystemen ergänzten sich. Durch den Testbetrieb konnten die Projektpartner Daten und Erfahrungen unter realen Bedingungen sammeln und gleichzeitig die Erwartungen an das neuartige Angebot regulieren. Die Komplexität des analysierten Akteur-Netzwerks zeigt, dass der Automatisierungsgrad nicht von abstrakten technischen Spezifizierungen abhängt, sondern von den materiellen Bedingungen des Betriebs und des Einsatzgebiets.

Abstract English

This study explores the sociomaterial practice of automated driving, its limitations and social dimension, by analyzing a specific case site: the public test operation of two autonomous minibuses in the urban development area Seestadt in Vienna. The auto.Bus Seestadt research project was pursued by an interdisciplinary team of six organizations and companies, among them the public transport service provider Wiener Linien and the Austrian Institute of Technology. This thesis aims at understanding how the project partners adapted the shuttle buses and the Seestadt quarter to one another. Employing classical actor-network-theories and related approaches to the study of urban spaces and infrastructures, the project partners are positioned as network builders who reassembled existing urban infrastructures with new actors and technologies to create the networked infrastructure of the test operation.

In order to understand the routine of automated driving, autoethnographic fieldwork in Seestadt was performed, including multiple rides with the buses. In addition, five problem-centered interviews were conducted. The sample included representatives of the project partners, one of the operators, and a researcher from the aspern.mobil LAB as a third party. The results show that automation is not a static feature of autonomous vehicles, but the outcome of translation and cooperation among a complex network of human and non-human actors. Seestadt as a smart city development area provided a futile starting point for the project and was further reassembled into an ideal test environment. The semi-regular transportation of passengers and the testing of automated driving systems reinforced each other, as the public operation allowed the partners to collect real-world data and experiences while managing expectations. The complexity of the network highlights that the level of automation is actually defined by the material conditions of the operation rather than abstract technical specifications.