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GreenTwin: Developing a Digital Twin for Sustainable Cooperative Mobility and Logistics in Rural Areas

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1 ABSTRACT

Public transportation is often poorly developed, especially in rural areas, which leads to an increased dependence on personal vehicles. Moreover, since transportation is one of the main drivers of climate change, our research project aims to explore cost-effective methods for sustainable last-mile logistics in rural areas and support decision-makers utilizing a dashboard. For this purpose, an open marketplace platform is planned that intelligently networks suppliers and service providers in a region and bundles orders and deliveries. The aim is also to motivate customers and users to behave in a more environmentally friendly way by suggesting appropriate offers through the way they are presented on the marketplace. This is achieved by integrating Digital Twin (DT) technologies, cognitive agent-based social simulation, transport management systems and recommendation systems. To ensure the project aligns with public needs and acceptance of proposed approaches, we conduct census-representative surveys alongside the development and experimentation phases. In this paper, the overall structure of the research project and the submodels underpinning our solution are introduced. It also includes a visual mockup of a rural region's DT and introduces several use cases.

Keywords: smart mobility, rural development, sustainability, planning, digital twin

2 INTRODUCTION

One main driver of climate change is transportation, which is responsible for approximately 25% of worldwide CO_2 emissions (Masson-Delmotte et al., 2022). This issue is particularly acute in rural areas, where reliance on private vehicles is high due to limited public transport and grocery store access (Süddeutsche Zeitung, 2022). Furthermore, rural areas in Germany usually have a higher proportion of commuters between and within its districts and go through more extreme demographic changes (Dauth & Haller, 2018), which makes the problem more prominent in the areas. Although alternative logistics approaches for the last-mile aiming at reducing costs or CO_2 emissions already exist (cf. Ranieri et al., 2018; Halldorsson and Wehner, 2020; Hepp, 2018; Frehe et al., 2017), most of those are not customised to rural areas or do not include concepts of heterogeneous products and groceries, which, for example, require compliance with cold chains.

Therefore, to alleviate this issue, our research project GreenTwin aims to explore cost-effective methods for sustainable last-mile logistics of various goods particularly in rural areas by considering unique regional characteristics (e.g., infrastructure and demographics) and needs of the inhabitants (e.g., dependency on private vehicles and long travel time). Additionally, it proposes a dashboard that displays information concerning the effects of different approaches to support stakeholders to make decisions. With the methods identified as effective, we expect the findings on mechanisms on promoting pro-environmental behaviours, strengthening regional businesses, and increasing the life quality of residents in the area.

This paper is structured as follows: Section 3 discusses the aims of the research projects as well as the methodology used. Section 4 presents the general structure of the research project consisting of several project phases and subsequently elaborates on these introducing the submodels underpinning our solution, required data as well as techniques for data acquisition. Furthermore, this Section includes a visual mockup of the solution, and the research projects use cases. Finally, Section 5 provides concluding remarks and an outlook on the next steps along with future work.

3 A TOOL FOR PLANNING SUSTAINABLE LOGISTICS IN RURAL AREAS

To address the issues mentioned in Section 1, our research project aims to provide an innovative solution that

(1) uses different optimisation techniques for minimizing greenhouse gas (GHG) emissions at the last-mile in logistic tours on a general level while considering the needs of actors involved (e.g., inhabitants and stakeholders);

(2) considers additional constraints that are incorporated by models of users via a cognitive social simulation;

(3) includes a novel marketplace concept and a model that captures links between sub services, end users and additional actors in a graph model, to enable a transparent and optimised end to end connection of sub services into one service for the end user that also displays the effects of connecting services.

One of the core tasks of this project is the development of a research demonstrator: the Digital Twin (DT) of the rural area. Additionally, we intend to place (physical or virtual) containers in the focus region that, among other services, provide goods for everyday use to decrease the need for running errands between communities. This would enable us to both pre-plan experiments consisting of scenarios and interventions within a simulation environment (DT) and to display it on a demonstrator for stakeholders in order to facilitate their decision-making and evaluate the findings, making use of the container setting in cooperation with regional partners. Evaluating the findings will provide local partners with a decent base for starting logistic cooperations. For instance, the containers are placed to minimise the necessity of traveling between different districts in the region for errands. The DT is thus planned to provide real-time ecological balance calculations for the optimization of various services and service chains. The outcome of such an evaluation of approaches is then shared with decision-makers using a dashboard. Within the framework of DT, agent-based modelling (ABM) as well as psychological and sociological theories are employed to represent both individual and regional characteristics at a more detailed level. ABM is especially useful when it comes to simulating heterogeneous population under certain circumstances as it is well-suited for illustrating a complex decision-making of individuals at micro level and resulting behaviour dynamics of the population at macro level (Smith and Rand, 2018).

Using a marketplace individuals can book orders from (regional) retailers by making a digital contract. Here, customers should be able to choose between different retailers based on various key indicators, for example, regionality, energy efficiency and price. Furthermore, transportation of the agents, especially when it comes to deliveries, is planned, and optimised using a transport management system within the DT. We aim to link combinatorial optimisation methods for logistics services (e.g., Multi-Commodity Flow Optimisation (Dziubany et al., 2020a)), agent-based (distributed) optimisation and heuristical optimisation methods as well as AI approaches (Maiorov et al, 2019; Stolfi and Alba, 2018; Mohammed et al., 2019). The goal is to develop AI-supported optimisation processes that align with both the overarching objective of minimization of GHG emissions and the individual, heterogeneous goals of users. This involves continual incorporation of the region and population's constraints, facilitated by integration with the DT. When first introducing new technologies or solutions, it is often a lengthy process that includes social skepticism (Lermer et al., 2015; Renn and Beninghaus, 2013), although advantages of those solutions are recognised by users (e.g., convenience, safety, costs, social participation, and environmental benefits (Lidynia et al., 2021)). Skepticism arises from, e.g., insufficient knowledge (Kyriakidis et al., 2015), concerns about dealing with data/privacy (Schomakers et al., 2018) or a missing inclusion of target users (Zaunbrecher and Ziefle, 2016). Hence, it is important to conduct research on the inhabitants' acceptance of potential services and their demand using census-representative surveys and interviews with other stakeholders and on how the acceptance rate can be increased in the best-case scenario. Additionally, the resulting data is used in the DT to model respective attributes of individual agents.

The outcome of this research comprises a dashboard designed for decision-makers to evaluate the impact of sustainable logistics concepts in rural areas. The dashboard provides real-time eco-balance calculations, offering a comprehensive view of the environmental impact of logistics operations. This functionality is crucial for decision-makers striving to balance ecological considerations with logistical efficiency. Our approach incorporates the diverse needs of both individual users and the broader population. By considering these heterogeneous demands, our optimisation processes could ensure a more tailored and inclusive solution for sustainable logistics in rural regions.

4 PROJECT STRUCTURE AND MODULES

Our research project consists of different phases, each dealing with specific tasks for the development process (see Figure 1).

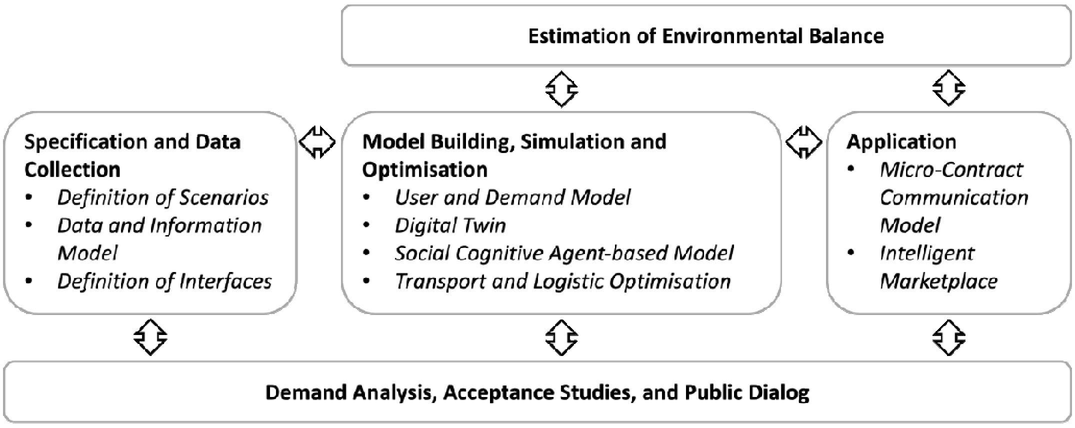

Fig. 1: Phases in GreenTwin

Each subsection of this Section focuses on one of these phases and presents details on the utilised methods. The Model Building, Simulation and Optimisation phase, which is further elaborated on in Section 4.1 summarises the submodels that are created from integrating DT technologies, cognitive agent-based social simulation, as well as network modelling and optimisation systems. The submodels are applied in an intelligent marketplace whose goal is to connect retailers, service providers and consumers of the region in the Application phase, which is discussed in Section 4.2. Scenarios concerning methods for sustainable last-mile logistics, the definition of interfaces between the models and required data are provided in the Specification and Data Collection phase. This phase is presented in Section 4.3. During modelling and application, we evaluate the different approaches based on GHG savings (Estimation of Environmental Balance), which is described in Section 4.4. To ensure the project aligns with public needs and acceptance of proposed approaches, we conduct census-representative surveys during the whole development process

(Demand Analysis, Acceptance Studies, and Public Dialog). These are introduced in Section 4.5. Additionally, Section 4.6. presents the visual mockup of the demonstrator of our solution consisting of a dashboard and different views of the marketplace solution.

4.1 Model Building, Simulation and Optimisation

User and demand model To effectively capture behavioural patterns of the rural model regions, it is crucial to base the user model and demand predictions on empirical data to ensure they are not only based on theoretical considerations but also on a regional understanding of the area and its social, economic and logistical processes. Therefore, this research project employs method triangulation, combining various types of empirical data for a comprehensive understanding (Baur & Blasius, 2019).

Conducted studies focus on the current state of people's mobility-, environment-, and shopping-related habits, which are critical aspects for the proposed application scenarios. Further, the research delves into the influence of social environments on decision-making. This aspect recognises that broader social dynamics often shape individual choices, adjusting personal behaviour to its societal context.

The methods employed include interviews, which serve to gauge stakeholder perceptions. The insights are validated through broader census representative online surveys to capture a wider population's viewpoints. Simultaneously, the local rural community is surveyed to explore region-specific prerequisites and behaviours. This part of the research provides insights into the community's current mobility and shopping habits and their attitudes towards environmentally friendly practices. The local perspective is vital for tailoring solutions and predictions to the community's unique context.

Finally, the design of all empirical endeavours is underpinned by psychological theories, including the Theory of Planned Behavior (TPB), Social Exchange Theory (SET), Theory of Reasoned Action (TRA), the Technology Acceptance Model (TAM), and the Unified Theory of Acceptance and Use of Technologies (UTAUT) (Ajzen, 1991; Davis, 1985; Emerson, 1972; Fishbein and Ajzen, 1977; Venkatesh, Thong, and Xu, 2016). These theories have been widely applied to explain engagement in sharing and collaborative consumption (Barnes and Mattson, 2017; Boateng, Kosiba, and Okoe, 2019), acceptance of last-mile delivery (Kapser and Abdelrahman, 2020; Hinzmann and Bogatzki, 2020), and mobility on demand (Ye, Zheng, and Yi, 2020; Nordhoff et al., 2021) – even though they mostly focus on an urban setting and the rural context remains underrepresented in the current research landscape. These theories guide the interpretation of the data and provide a structured framework for the entire research process, connecting the empirical findings to broader theoretical constructs.

Digital Twin and Social cognitive Agent-based model For testing different scenarios and interventions, a DT is used as a virtual representation that reflects the situational characteristics and individual decisions in the corresponding region in order to support decision-makers (cf. Wang et al., 2023). Since we focus on rural areas in Germany, we consider distinctive characteristics that set them apart from more densely populated or urban areas. First, rural areas in Germany usually consist of multiple small communities, which often have a poorly developed public transport infrastructure. Moreover, these rural areas are characterised by demographic changes, such as rural migration, including extraordinarily high numbers of commuters (Dauth and Haller, 2018). The existing body of literature concerning DTs of inhabited areas predominantly concentrates on urban environments, there arises a necessity for a model that considers the unique characteristics of rural areas, addressing this gap in research (Rodermund et al., 2024).

In GreenTwin we develop a multi-layer DT framework that enables experimenting with various scenarios and intervention approaches promoting pro-environmental behaviours among rural areas' inhabitants. In each layer of the framework, we address one essential factor required for representing such areas and the complex interplay between these decision-relevant factors. For instance, the region, infrastructure, and its specifics are modelled in a spatial layer, the inhabitants of the region as well as people commuting within and between communities are included in the individual layer. Because we aim at integrating the influence of the social network (e.g., neighbours, family, and friends) on individual decisions, we additionally include a social layer for the region's DT.

The spatial layer builds the foundation for the individual decisions made in the DT as it determines the individual's options by defining the situational circumstances. Here, private as well as public areas (e.g., households, neighbourhoods, workplaces, and places of interest (POIs) like supermarkets) are located. The communities' infrastructure, consisting of streets and public transport, connects these individual locations.

To represent people of interest in the individual layer we make use of Agent-based modelling (ABM) and Multi-agent systems (MAS), as these methods have established themselves in representing complex cognitive decision-making (Bonabeau, 2002; An, 2012). Additionally, we employ psychological theories explaining factors relevant in the decision-making for or against pro-environmental behaviours. To adequately incorporate those theories in an agent architecture we make use of the Belief-Desire-Intention (BDI) model (Bratman, 1987). BDI organises individual goals (desires), information (beliefs) and action-oriented measures (intentions) into mental states, whereas in a deliberation process intentions are derived from beliefs and desires (see, e.g., Bratman, 1987; Berndt et al., 2018). The spatial and individual layer are linked by the social layer. This layer is particularly important for our use case because the communication within social networks plays a crucial role in shaping pro-environmental behaviour (see, e.g., relevance of social norms (Cialdini and Jacobson, 2021), or social learning (Chwialkowska, 2019; Zhang et al., 2021) or even in the diffusion of information and new technological solutions (Rogers et al., 2014). The inclusion of such concepts and theories as social norms and social learning into MAS leads to Agent-based Social Simulation (ABSS) (Davidsson, 2002). ABSS is highly suited for representing interactions between individual agents under consideration of social concepts and it ultimately enables us to conduct experiments concerning different scenarios while taking both psychological and social aspects into account (Squazzoni et al., 2014).

To verify assumptions made in the process of conceptualizing and modeling there is a variety of data sources utilized. For instance, in the spatial layer we combine OpenStreetMap[1] (OSM) data and census data[2] to create the physical environment as well as the initial population. The individual layer requires data from empirical studies to model daily schedules as well as the agent's decision process. Furthermore, to determine actual places the agent travels to for work, necessary and leisure activities, statistical data (e.g., Pendleratlas[3] (Commuter atlas) or Datenreport Umwelt, Energie und Mobilität (Data report environment, energy, and mobility) (Brockjan et al., 2021)) is used. For the social layer, additionally to the data retrieved from the spatial layer, we also make use of empirical data. The empirical studies that are to be conceited in this project are further discussed in Section 4.5. For validation we intend to use publicly available data (statistics, that have been introduced before, e.g., commuter statistics, OSM or census data) as well as traffic count data from the respective rural region. Additionally, an extract of the empirical study data is employed for this purpose, too.

Transport and Logistic optimisation In the area of transport and logistics optimisation, the focus is on optimising the structure of logistics networks (i.e., the selection of suitable hub locations), the consolidation of transport requirements and the actual execution of the resulting transport shipments.

When it comes to passenger transport, aspects such as customer decisions must also be taken into account when optimising a service. Short-notice bookings or cancellations in particular can mean that a mobility service is no longer economically viable. Here, flexibility and convenience for customers must be balanced with efficiency and thus the cost-effectiveness of the service. Preliminary work already exists in this area that deals with the use of flexible time windows for the planning of passenger transportation. Here it was investigated how users can be offered shared rides within time windows of maximum size, while at the same time maintaining the flexibility and profitability of the system (Dziubany et al., 2020b). A Mobility on Demand service places even higher demands on optimisation, as online optimisation is required to adjust vehicle routes in near real time. Various approaches exist for this, including queuing theory (Iglesias et al., 2019), simulation-based approaches (Tilg et al., 2020) and multi-commodity flow problems (Stenberg et al., 2021). In this context, we plan to research optimisation methods that enable an online solution for on-demand mobility and also take into account rebookings and cancellations while maintaining the profitability of the overall system. The integration of heterogeneous players, such as private and commercial drivers, and networking with public transport services should yield the system to be highly flexible. Preliminary work has

[1] https://www.openstreetmap.de/
[2] https://ergebnisse2011.zensus2022.de/datenbank/online/
[3] https://www.pendleratlas.de/

already been carried out on the integration of private and commercial mobility services. The study by Gu et al., 2024 examines algorithms that optimise matches between drivers and passengers based on their time constraints. It also minimises travel time and operating costs while integrating public transport with cars and ride sharing services. Such Mobility as a Service (MaaS) platforms are becoming more and more widespread. In their work, (Cruz et al. 2020) analyse typical challenges of such platforms and how they use sharing concepts for maximum flexibility. They also present various business models that can emerge in this environment.

To this end, existing algorithms of the PSIglobal software application are being further developed for use in passenger transport and last-mile logistics. Furthermore, detailed emission tariff functions are generated and parametrised to be able to carry out optimisation calculations not only based on costs, but also with regards to sustainability (GHG emissions). Finally, possibilities are to be created to be able to interactively adapt an already modelled logistics network during operation at short notice so that the effects on essential KPIs (e.g., costs / GHG emissions, resource utilization, pick-up and delivery time windows, ...) are recognizable.

In addition, an event-based model of mobility and logistics processes is being developed in the project so that manual scheduling of transport orders is possible in addition to automatic scheduling.

4.2 Application

The newly developed services are to be made available via an open marketplace platform. “Open” means, that both private customers and providers as well as commercial providers can use the platform to purchase or offer products and services. The marketplace platform is connected to the DT and uses optimisation and recommendation algorithms to display suitable offers to users. The individual services are not treated isolated, as the marketplace is expected to have a network effect. The central platform instead of separate platforms should increase the likelihood that users will use several of the services on offer. In addition, some aspects of the scenarios considered are interdependent in terms of environmental effects or logistics. By taking a holistic view through simulation and evaluation, the DT can represent the region in a more accurate way. Offers are supposed to be tailored in a way that they have a positive effect on the overall system, considering logistics, emissions, market situation and personal preferences. In order to make this process transparent and to encourage users to decide based on these aspects, metrics such as CO2 balance or personal saving opportunities should be openly displayed. Regardless, users will also be able to actively search for other offers and services and select them. Figure 2 displays the overall structure of the marketplace platform and its interfaces to the systems around it. The DT covers various scenarios, including product delivery service, share economy and mobility on demand, and could also use third-party data via interfaces, including markets and mobility service providers. Those scenarios addressed here are introduced in more detail in Section 4.3. The information from the DT is incorporated into the marketplace in order to regulate it, for example by creating new offers or adapting existing ones, or by displaying more suitable offers to users first. Users access the offers of the marketplace via a contract framework, which is described below.

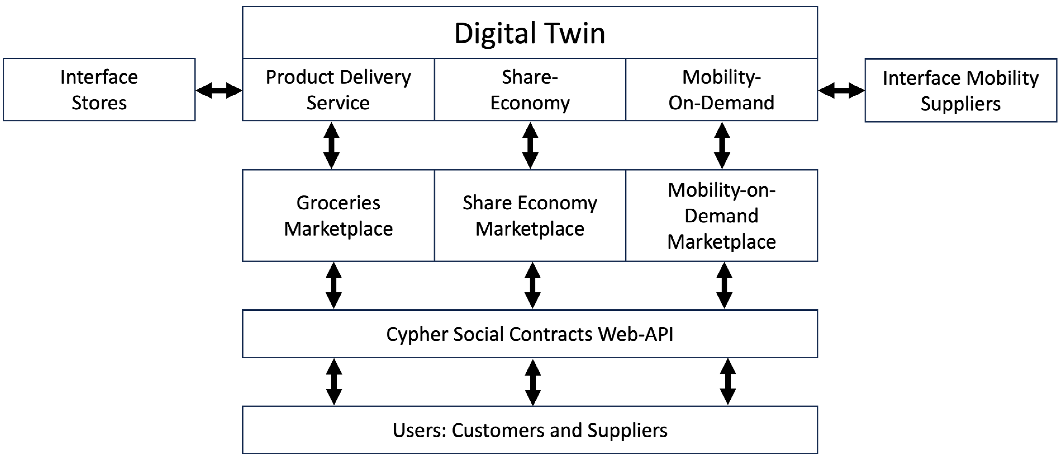

Fig. 2: Structure of the Marketplace Platform

The various offers and services on the marketplace require communication between the parties involved. For this purpose, an open source framework for cypher social contracts is going to be used (Creutz et al., 2021).

The framework enables generic digital contracts between two parties that can be written in natural language. The contracts are private through strong encryption and forward-secrecy and are automatable and can therefore also be used for contracts between humans and machines or machines only. In contrast to many other smart contract protocols, this system does not require blockchain or similar technology. This makes the system extremely energy-efficient and allows it to run on IoT hardware and even be used over limited bandwidth channels, such as LoRaWAN via a middleware (Creutz et al., 2022). A legal audit by the University of Frankfurt also confirmed that the contracts concluded using this framework can be legally valid (Spiecker et al., 2023). Contracts are derived from templates that specify the structure of a contract, i.e., the contractual steps included and the responsibilities of the parties for each step. A contract can then be seen as an instance of such a template. During this project, the described contract framework is to be integrated into the intelligent marketplace and forms the backbone of the marketplace's communication infrastructure. In summary, the use of this micro-contract system enables a private, secure, and legally binding method of carrying out transactions on the intelligent marketplace.

4.3 Specification and Data Collection

In the realm of DT technology, the significance of both the quantity and quality of data cannot be overstated, particularly in the context of developing agents and models integral to its framework. The efficacy of ML algorithms, a cornerstone in the functionality of DTs, is heavily influenced by the dataset's volume. This emphasises the need for a careful specification of the scenarios, aiming to define the required data sources that are crucial for the investigation. Such a strategic approach facilitates the establishment of a comprehensive data management concept, encompassing data structure organization, tailored explicitly to the objectives inherent to each specified scenario. This methodology ensures a robust foundation for the operational efficiency of DTs, thereby enhancing their reliability and applicability in simulating and optimising real-world processes. Even though the DT and marketplace are intended to cover the entire spectrum of last-mile logistics and mobility in the future, in our research and implementation, to cope with the enormous complexity of our designed application, we are focusing on four representative example scenarios. These example scenarios are to be fully implemented within the first version of the project and tested and evaluated in pilot operations. The scenarios were chosen to cover as many aspects of future use cases as possible and thus enable a representative study of the overall project. Specifically, this pertains to the domains of the sharing economy, demand-driven product management, logistics planning for delivery services, and a scenario involving mobility on demand, all of which is explained in more detail in the following.

Share Economy: Many households have a range of expensive items that are only used rarely or for limited periods of time. These include, for example, various types of tools such as drills, saws or lawnmowers, or sports and leisure equipment such as kayaks or camping equipment. These are just a few examples that clearly show that there are items that should be shared with others rather than owned, to save resources both economically and environmentally. The underlying idea is, that both private and commercial providers (e.g. DIY stores) can offer such items for hire. The items can then be rented out via a booking system that is integrated into the marketplace. They are stored in intelligent networked lockers located in the local hubs close to the customers. This system is supported by the DT, which maps demand and distributes the goods to the hubs via an intelligently controlled delivery fleet. From a systems perspective, a DT of the population is needed for several purposes. It serves to determine the demand of a community and, based on that, to develop a recommendation engine integrated into the marketplace. This offers customers, for example, renting as an alternative to purchasing products. Additionally, an intelligent fleet management system is required that distributes goods and shares resources with other services, such as food delivery, to be more efficient.

Demand-driven product management: Many supermarkets align their product range nationwide which leads to food waste. Local supply, in contrast, offers the opportunity to tailor product ranges very precisely to actual needs. By understanding the preferences of the specific target group and aligning the product ranges accordingly, food waste can be reduced. At the same time, the need to travel to distant stores for certain products can be counteracted to a certain extent and the reliance on private vehicles for basic supply can be reduced as well. This requires the DT to learn and map the local target group, e.g., inhabitants of a village, along with their needs. By sharing knowledge across several local models, incentives for new products can also be derived. For example, a new product can be introduced in a smart hub for testing, because it has performed well in other smart hubs with a similar target group. On the system side, local models could be developed. This could make the use of federated learning in this scenario beneficial.

Planning of delivery services: An open marketplace platform and an optimised shared delivery service could break the monopoly of large online marketplaces, such as Amazon or wholesale chains in favor of local providers. Thanks to the DT, the online marketplace can learn the needs and preferences of individual customers. In based on customer purchase behaviour, representing customer preferences and capable of being integrated with additional local models. This way, purchases from different retailers can be bundled and delivered together. The delivery fleet could be a combination of professional delivery services and takeaway services, e.g. by integrating commuters. Deliveries could also be bundled by delivering to smart hubs, which should be particularly convenient for customers with busy schedules, similar to DHL lockers. Deliveries could also be made to the front door, for example for elderly or people with mobility impairments. What is needed here, is an agent-based DT for granular mapping of needs and preferences at customer level, which can be ensured by using the marketplace. In addition, route planning in conjunction with intelligent fleet management, that can handle heterogenous fleets, consisting of delivery networks and private people, is required.

Mobility on Demand: In the rural model regions, public transport coverage is not developed well enough to provide a viable alternative to private vehicles. The time intervals between services are too long and, due to the many scattered villages, the journey times are also too long. For reasons of time and flexibility, most people therefore rely on private vehicles. This poses a problem for older people or people with disabilities, as well as people with limited financial resources, and impairs their quality of life. A highly flexible and affordable mobility service could provide a remedy here. A system for booking journeys integrated into the marketplace is indended to be combined with intelligent route planning. Private individuals can also be involved as drivers. A service as such should not compete with public transport but should complement it in a reasonable way. On the system side, the DT helps to anticipate requests and bundle journeys. Journeys should be bookable both in advance and at short notice. This requires advanced optimisation processes that can also respond to last-minute requests and cancellations while remaining profitable.

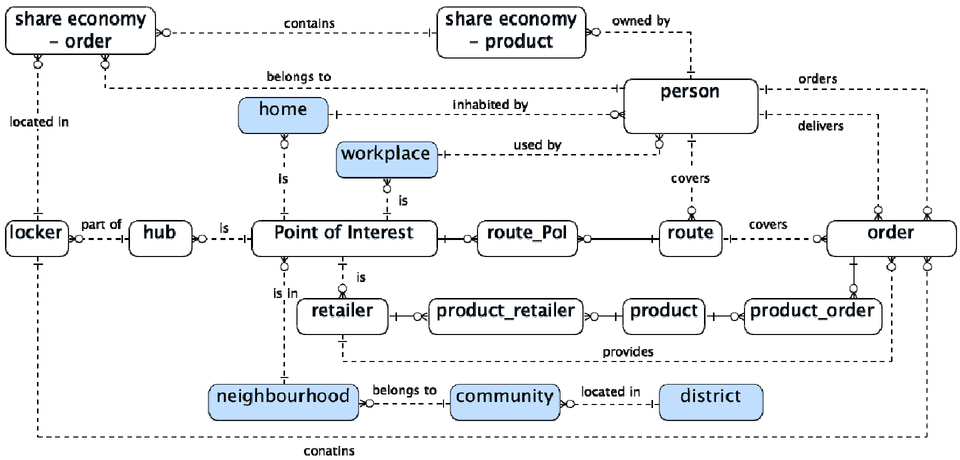

Fig. 3: GreenTwin Cross-Scenario Database Schema

Each of the previously defined scenarios contains components that must work together, but at the same time place different demands on the database. For this reason, a system is being developed that links different data structures with each other. This means that only data relevant to the respective task of a component is processed to ensure maximum efficiency and resource conservation. However, the scenarios can also benefit from data recorded in other scenarios. Our approach is to implement a system that connects the marketplace platform with a database and a knowledge graph (see 4.2). The simplified database schema is shown in Figure 3. It contains information about people and their routes, products, providers, and hubs. The marketplace platform is the interface to the users and accesses the database. Interactions such as inquiries or offers lead to the information within the data structures being modified and, if necessary, expanded. If, for example, a user inquiry is made on the marketplace platform, this is transmitted as a query to the knowledge graph, which contains personal information and preferences as well as product and supplier information. The response then contains offers individually tailored to the user. The connections, weightings and attributes within the knowledge graph are changed by user decisions and thus continuously improved. The amount of data increases with each user interaction, which leads to a larger amount of training and therefore also to an improvement in the algorithms.

4.4 Estimation of Environmental Balance

The conception of the DT is predicated on enhancing real-time environmental impact evaluations within the logistics domain, encompassing the distribution of goods and regional service provisions. Its mechanism includes integrating environmental assessments into optimisation algorithms and elevating the ecological impact to a critical parameter within these computational processes. This integration makes a decisive contribution to supporting the introduction of sustainable logistics methods that meet the increasing demands for environmental compatibility. A key innovation in this area, our research project, is designed to help the consumer decision-making process by providing transparent insights into the environmental impact of different services. Such transparency is expected to create a market with increased sensitivity to sustainability issues. The underlying AI model will be designed to ensure flexibility across various logistical configurations and its applicability and effectiveness. The project provides for a review mechanism to underline the scientific integrity of the environmental assessments. This step is essential to drive a paradigm shift towards sustainable logistics and service models. This will contribute to the discourse on developing a DT for sustainable cooperative mobility and logistics in rural areas and provide a novel approach to mitigating environmental impacts through technological innovation and scientific validation.

4.5 Demand Analysis, Acceptance Studies, and Public Dialog

Innovations usually face skepticism, especially if they are not well communicated or seem to be solely based on developers' and/or specialists' ideas (Gulari et al., 2011). Many studies have shown, however, that the involvement of the intended users as early as the development can help facilitate a better product, in the sense of usability, and also a smoother roll-out (Rohracher, 2005). In rural regions, technology awareness, roll-out, and attitude differ from those of city dwellers (Porru et al., 2019). Therefore, a crucial part of this project is the involvement of the public who are the target users.

Thus, the first step after thinking of a possible solution for a more sustainable and environmentally friendly way to ensure supply in rural regions of Germany, is to conduct a demand analysis. What is missing and what, specifically, do citizens wish was improved. That way not only does one a) get to know the target group but also b) their needs and demands. While the first part (a) also facilitates a blueprint for the DT, the second part (b) can help to understand acceptance or rejection of the innovation.

In most cases, acceptance studies are based on acceptance models, especially established technology acceptance models such as TAM (Davis, 1985) or UTAUT (Venkatesh et al., 2016). They survey different variables to understand why people would want to use a technology (e.g. Turner et al, 2010). In case of AI and mobility, those acceptance models have to be extended as, for example, trust has not been a traditional part but was shown to be a strong predictor (Brell et al., 2019). Other context-relevant aspects need to be included to understand if and to what extent they influence the acceptance and willingness to use and participate in the innovation.

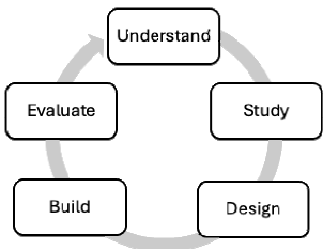

Fig. 4: Structure of the Empirical Research Approach

It is important to include the public early on and use different methods to do so, from demand analysis (what do people need, want, and expect), to acceptance studies (what factors influence the projected willingness to use the technology/innovation and perhaps change habitual behaviours), to finally communicate and offer transparency of the ideas, methods, and outcome or results of the use of the proposed innovation. This iterative approach and design cycle (see Figure 4) has been shown to be very valuable to successful research and development (c.f. Courage, C & Baxter, 2005; Harper et al., 2008).

4.6 Dashboard: Visualising Pro-Environmental Behaviour

As mentioned in Section 3, one outcome of this research project is the provision of a dashboard that supports decision-makers by means of comparative analysis of different scenarios and interventions in terms of various relevant key indicators. Additionally, our marketplace solution connects users (end customer) and providers by placing tailored offers as well as tracking and visualising personal reduction in CO2 emissions. Figure 5 shows those different views:

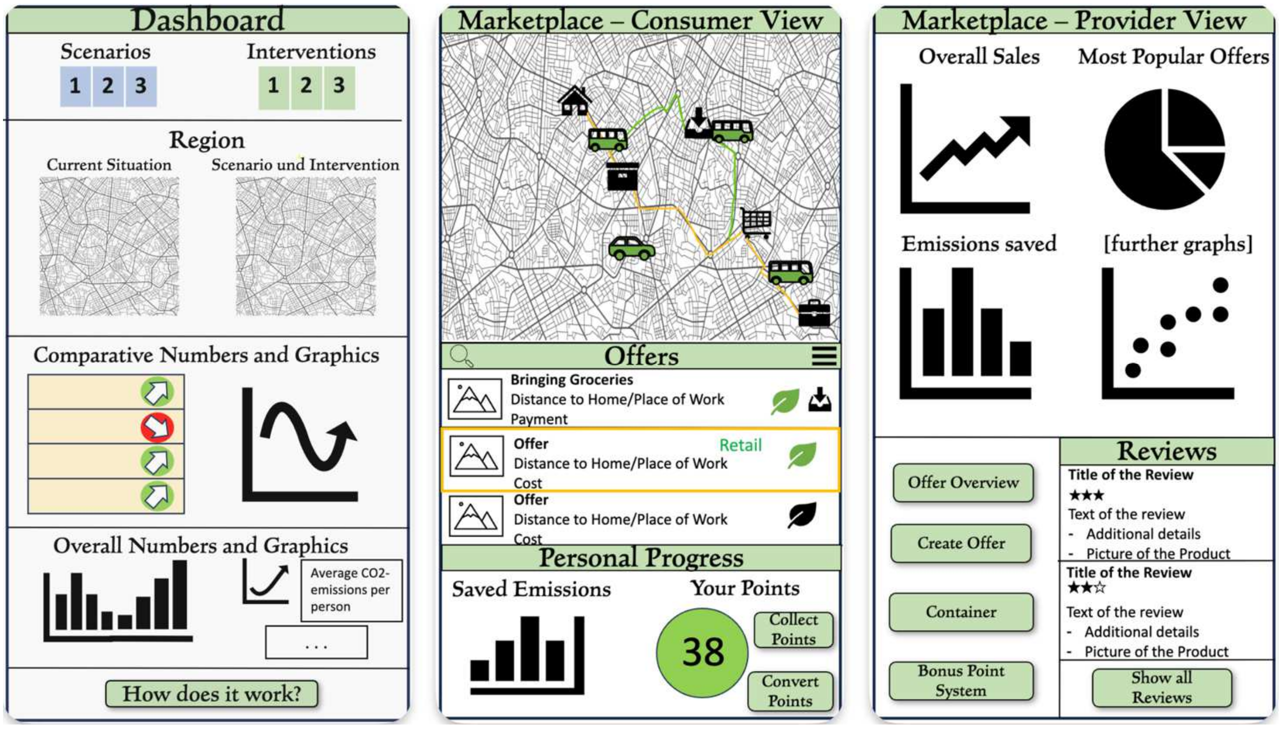

Fig. 5: Visual Mockup of Dashboard (a), Consumer View of Marketplace (b), and Provider View of Marketplace (c).

(a) The Dashboard interface is segmented into five sections. Users have the option to select from a variety of scenarios and interventions for evaluation, which are then visually represented. The second section presents dual map views of a specific region; the left map displays the region in its current state without any interventions, while the right map illustrates the region post-intervention application. Enhanced visual elements, such as color-coded districts/routes/communities, will be utilised to represent the key metric: CO2 emissions. The third and fourth sections offer a comparison of variable changes between the two maps and display relevant indicators for the region post-intervention. The final section is designed to provide users with a detailed explanation of the dashboard's functionality and the underlying DT technology.

(b) The Consumer View of the Marketplace summarises information relevant for customers. It facilitates the placement and acceptance of offers among neighbours or local providers. The map view can be used to show them the most environmentally friendly routes to take for each task, as well as nearby alternatives to travel such as public transportation. Users can add their home address and place of work to the map, to further calculate best routes. Routes are color-coded, with green indicating the most sustainable option and yellow representing the user’s regular travel path. The map also marks local stores and Shared Economy containers. Users can pick offers and services based on environmental impact and can collect points by choosing options with less CO2 emissions than an average alternative. Those offers are marked with a green leaf, whereas offers that would not lead to any saving of emissions are marked with a black leaf. If possible, participating providers could offer users to exchange these points for rewards at their stores.

(c) Providers themselves have an overview on the benefits of the project for themselves, such as sales data and CO2 emission reductions. Additional options might be to create a new offer, show an overview of current offers and manage a bonus point system and show reviews of previous customers. They can further access the container-system, which allows for a Share Economy System, as introduced in Section 4.1.

5 SUMMARY

In this paper, we introduced the GreenTwin project which aims to explore methods for sustainable last-mile logistics in rural areas that benefit both residents and other stakeholders by improving local supply and supporting logistic decisions that are cost-efficient as well as environmentally friendly. For this, we combine agent-based simulation, cognitive modelling of the population, and optimising logistics processes as primary methodologies. This paper outlined the project's development phases and discussed the submodules and used methods as well as how these are combined to an overall solution. Since this research project is still ongoing, whereby some challenges must be acknowledged. For instance, our solution requires merging of data from various data sources with different granularity to mirror the real-world rural region in our (sub) models. Hence, we plan on maintaining a collaborative data concept to control information flow between the submodels. Furthermore, as it is challenging to adequately prepare information on effects of different logistics services to provide a robust and transparent basis for decision-makers future work thus includes the design and development of visual components and relevant information in dialogue with stakeholders (e.g., through workshops or studies/surveys). Lastly, in this research project we aim at providing a solution as a pilot demonstrator to prove the applicability of the overall solution in a model region. Hence, this project may therefore be followed by the further development of the solution into a prototype in the target region and extensive testing under real conditions.

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